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U N I V E R S I T Y O F A L B E R T A

F A C U L T Y O F A R T S A N D S C I E N C E S.

The undersigned hereby certify that they have read and recommend to the Committee on Graduate Studies for acceptance, a dissertation on "Some Factors in Briquetting" submitted by W. A. Lang, B. Sc., in partial fulfilment of the requirements for the degree of Master of Science.

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S O M E F A C T O R S

I N

B R I Q U E T T I N G.

B y

W. A. L A N G, B. Sc.

U N I V E R S I T Y O F A L B E R T A

Edmonton, Alberta.

1925 - 1926.

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P R E F A C E.

The following thesis is based on the work carried out by N. H. Atkinson, session 1922-1923, W. L. MacDonald, session 1923-1924, F. L. Grindley, May to October, 1924 and W. A. Lang, November 1924 to date.

Briefly, the investigation, which is still in progress, is an attempt to put the art of briquetting on a scientific basis by means of a study of the important factors which influence the making and testing of briquettes. The investigation has also included a study of different materials that might be used as binders and of the physical properties of representative binders.

It has not been felt necessary to enter into a general statement of the problem under investigation with its commercial application, as these have already been sufficiently treated in a thesis submitted by Mr. N. H. Atkinson, entitled "Carbonizing & Briquetting".

Six hundred and seventy-four runs of briquettes have been made since the commencement of the investigation. Runs numbered (inclusive) 1-118 were made by N. H. Atkinson, 201-306 by W. L. MacDonald, 307-446 by F. L. Grindley and 447-756 by W. A. Lang. It is not always convenient, in the discussion of the results, to state the experimenter's name, but by reference to the run number, credit may be given to the person who did the work. It will be noted, however, that the results of the more recent work are given wherever possible, because as the work progresses the technique improves, and more complete records are kept.

The investigation was carried out in the laboratories of the Industrial Research Department under the direction and supervision of Prof. Edgar Stansfield, with the assistance and cooperation of the members of the Industrial Research Department and of Prof. Pitcher and Associate Prof. Cameron of the Mining Department.

The writer wishes to acknowledge his indebtedness to the above for the cooperation, helpful advice, and kindly criticism, which have been of much assistance in the preparation of this thesis.

SOME FACTORS IN BRIQUETTING.

Chapter I. Briquetting.

Introduction.

The process of briquetting consists of adding to a suitably sized coal the desired percentage of binder, either crushed or molten, of mixing the mass thoroughly at raised temperatures and of pressing the plastic mass into briquettes. The briquettes are then screened, cooled and stored.

In general, it may be said that the production of briquettes depends upon the following factors:

(1) The equipment used, and its efficiency.
(2) The nature and sizing of the coal to be briquetted.
(3) The binder.
(4) The method of procedure in mixing and pressing.
(5) The product required.

Equipment.

The material to be briquetted, the binder available and the product required largely predetermine the equipment employed, and the procedure to be followed.

The machines used in mixing and pressing are the important parts of a briquetting plant.

In commercial practice three types of mixers are commonly employed, viz., horizontal helical mixers, vertical or horizontal fluxer with revolving and stationary arms, and edge-runners or masticators. These mixers are usually steam-heated externally. In most plants steam can also be passed into the charge in one or more of the mixers.

The mixing equipment in this laboratory consists of two of these, a horizontal helical batch-mixer, and a vertical fluxer.

Three types of presses are in general use, namely, high pressure extrusion presses, plunger presses and roll presses.

High pressure extrusion presses are being used extensively in European countries, especially in the briquetting of the self-binding lignites of Germany. This coal is partially dried and then briquetted by using high pressures but no binder.

Plunger presses were used first and were designed for large briquettes, but when the demand was made for smaller briquettes, a change in the type of machinery used was necessary in order to maintain large production.

Roll presses consist of a rotary machine with two rolls each containing a large number of pockets formed on its face and with one roll revolving against the other. The advantage of this design is that a larger production of small briquettes can be obtained, less power is required, and the briquettes can be made of a good shape for handling and firing, but a disadvantage, particularly for research purposes is that there is no accurate means of regulating the pressures.

In this laboratory a small plunger press is used.

Detailed descriptions of the equipment used in the experimental briquetting work here have been given in "Carbonizing and Briquetting" * and in the Third, Fourth and Fifth Annual Reports of the Scientific and Industrial Research Council of Alberta.*

Minor changes have been made from time to time. During 1924

*Atkinson, N.H. Carbonizing & Briquetting, P. 33.
Scientific & Industrial Research Council of Alberta, Third Annual Report p.34
" " " " " Fourth Annual Report, p. 28
" " " " " Fifth Annual Report, p. 28

the 10 H.P. motor was replaced by a 15 H.P. motor. Two new springs were installed, spring #3 in 1924 and spring #4 in 1925. Both springs were calibrated in the Civil Engineering Laboratories through the courtesy of Prof. R. S. L. Wilson and Prof. I. F. Morrison. These changes enabled higher pressures to be used as is shown in Fig. I.

The feed-hopper supplied with the press had a number of rotating padales to force the mixture into the die-box. As considerable trouble was experienced with this arrangement due to erratic feeding, the feed-hopper was substituted by a simple sheet-metal chute to allow the mixture to enter the die-box by gravity. Two difficulties were experienced: the temperature control was erratic, and a dry, powdery mix would not feed.

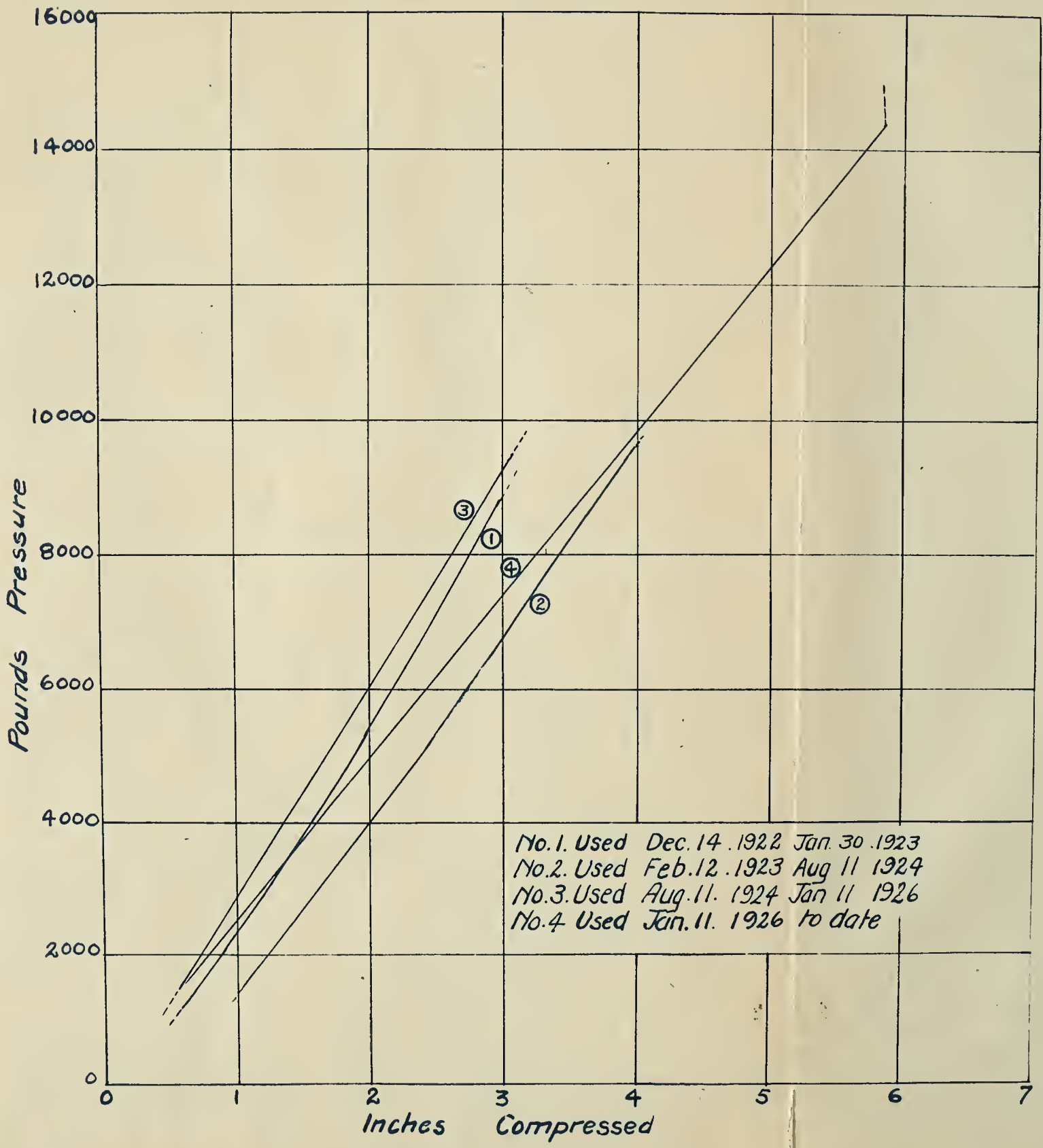
The use of the fluxer was discontinued because it was found that the temperatures could not be easily controlled and that the abrasion of the binder-coated particles in the fluxer exposed fresh, uncoated surfaces which materially reduced the quality of the briquette.

When the use of the fluxer was discontinued the mix was dumped directly into a steam-heated mix-can and hand-fed to the press. This method proved very satisfactory, giving a more accurate temperature control, a more uniform size of briquette, and made it easier to vary the conditions of pressing.

P r o c e d u r e.

The normal procedure of a test has developed to be as follows:* The coal is crushed to the desired size and its screen analysis determined with Tyler standard screens in a ro-tap shaking machine. In the majority of cases, coal of a desired screen analysis is prepared

* Scientific & Industrial Research Council, Fifth Annual Report, 1923, p. 28.


16000
14000
12000
10000
8000
6000
4000
2000
0
Pounds Pressure
0
1
2
3
4
5
6
7
Inches Compressed
③
①
④
②
No.1. Used Dec. 14 .1922 Jan. 30 .1923
No.2. Used Feb.12 .1923 Aug 11 1924
No.3. Used Aug.11. 1924 Jan 11 1926
No.4 Used Jan.11. 1926 to date

by first screening the crushed coal into the various sizes over Tyler standard screens on a small Marcus shaker screen and then mixing together the desired weights of each size of coal. A weighed quantity of coal (usually 8 kg.) is then placed in the steam-jacketed mixer, where it is mixed and heated. The binder, or binders,* are added, also water if desired, in weighed amounts and in the order arranged. Mixing is continued usually for two or three minutes, and the temperature raised to the required degree, the temperature being measured by a thermometer immersed in oil in a guard-tube which projects into the mixed mass. The charge is then dumped into a steam-heated mix-can and hand-fed to the press at the rate required to make a standard-sized briquette every stroke. Records are kept of the mixture made, order of mixing, time of mixing, temperature at each stage, and particularly the temperature of the mix as it goes to the press; also, any special points observed during mixing and the behaviour of the mix in the press. A sample of the mix just before going to the press is taken and placed in an air-tight container for moisture determination. (Until recently a small sample of the briquettes were taken and weighed, the moisture lost during air-drying, and the moisture retained after air-drying determined.) The method adopted gives a more accurate determination of the moisture in the mix. It is also more convenient to take moisture samples in this way.

When the bulk of the briquettes have air-dried to normal conditions, (one week has been found sufficient for this), samples are tested in the rattler machine for abrasion loss, in a furnace to

*Note: The amount of binder used in all cases is expressed as number of parts by weight of the binder added to 100 parts of coal. This is termed the "mixing ratio".

to determine firing qualities, in a close retort for smoke and coking tests, and in the laboratory to determine real and apparent specific gravity and also porosity. In some cases a sample is exposed to the weather for a few months and then tested in the rattler for comparison with the rattler results on the original briquettes. Briquettes are regarded as satisfactory when the tests indicate that they can be handled and shipped without serious abrasion losses, will burn well in the fire without falling to pieces and can be stored exposed to the weather without notable deterioration. A briquette, otherwise satisfactory, that does not lose more than 20% in the rattler test is regarded as strong enough to be handled and shipped.*

C o a l - nature.

The nature of the coal is an important factor in briquetting because the properties of the briquette are the properties of the coal plus the properties of the binder, also it is an important factor in determining the quantity of binder required in the process.

Coal ranging from anthracite to lignite varies considerably in physical properties. The important physical properties are: (1) density, (2) fracture, (3) hardness, (4) porosity, (5) analysis, ash, moisture and volatile, (6) coking properties, (7) resistance to wetting with water.

(1) Density.

For the same weight of coal the amount of surface to be covered by the binder varies inversely as the density of the coal, other things

* Footnote (1): It is necessary to state that only the results of runs of briquettes made under similar conditions can be compared because of the many variable factors.
(2) To avoid confusion, only the factors being considered will be included in the tables given.

being equal. In general, the density of a raw coal increases ~~with~~ with increase in carbon, but there are many other factors upon which it will depend. Among the more important are kind and percentage of ash, moisture and porosity. Other factors being equal a comparatively small change in the quantity and nature of the mineral matter present may make a large change in the density of the coal. Coals which are high in moisture when mined, also change rapidly in apparent density as they dry out and become porous. Carbonized fuels are very porous.

T A B L E I.

Apparant Specific Gravity & Ash Content - Greenhill bituminous coal.

Per Cent Ash (as received)	App. Sp. Gr. (as received)
4.9	1.29
6.4	1.32
18.0	1.41
53.3	1.75
67.8	2.01

T A B L E I I.

Real Specific Gravity, Apparent Specific Gravity and Ash Content
Penn Mine lignite coal.

% Ash (Air Dried)	Real Sp. Gr. (Air Dried)	App. Sp. Gr. (As received)
3.1	1.46	1.30
3.8	1.50	1.30
4.3	1.52	1.32
6.7	1.50	1.41
8.5	1.79	1.56

T A B L E I I I.

Real Specific Gravity and Ash Content - Coal Valley sub-bituminous coal.

% Ash (As received)	Real Sp. Gr. (As received)
11.9	1.45
16.4	1.50
18.7	1.50
34.7	1.71

This work was undertaken only recently and complete data have not been secured. The above results, however, indicate the importance of density determinations,, as it has been observed in the experimental work that good briquettes can be made with a less mixing ratio by weight of binder when a high density coal is used than when a low density coal is used.

(2) Porosity.

It is known that porous materials require binder to fill the pore space, but no measure of the porosity of coals has been determined.

(3) Fracture.

Coals fracture differently and this may be a factor in the closeness with which the particles will mesh together. This factor has been observed, but no attempt has been made to study its importance.

(4) Hardness.

A hard coal does not crush easily in mixing and pressing, thus exposing fresh surfaces to be covered with binder. The hardness of the particles also gives strength to the briquette. Hard abrasive material like coke breeze, etc., cause serious wear on the plungers.

Tests were made to show the amount of crushing undergone by two types of coal, namely a sub-bituminous coal from Coal Valley, and a semi-anthracite coal from Canmore. The Canmore coal, because of its geological history is very friable and crushes considerably more during the same period of mixing and under the same conditions of pressing than does that from Coal Valley, as is shown in Figures 2, 3 and 4. The amount a coal will crush during mixing and pressing will be a determining factor in deciding the original sizing of the coal best suited for the briquetting of it. Thus the correct proportioning of the sizes with a hard coal is more important than with a soft coal, and must be closer to the ~~optimum~~ sizing of the coal desired in the briquette.

(5) Analysis.

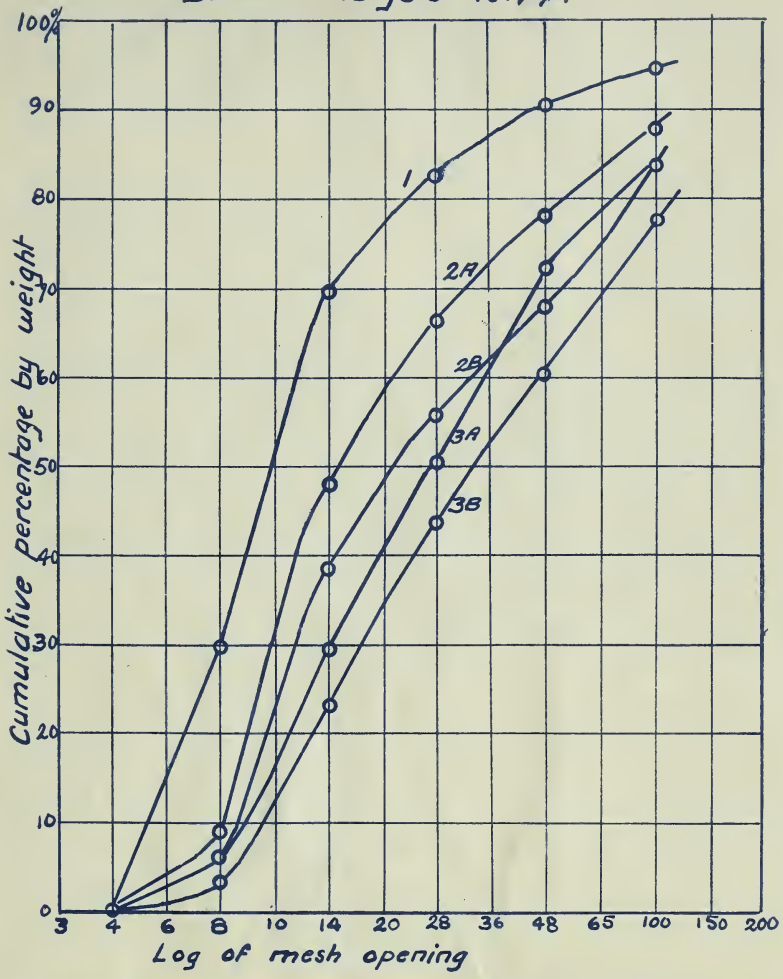
(a) Ash: Besides having the same detrimental effect, a high ash content is just as undesirable in briquettes as in coal, but ash in the coal to be briquetted also causes a waste of binder as is shown in the following table.

T A B L E I V.

Ash Content and Binder Requirement .

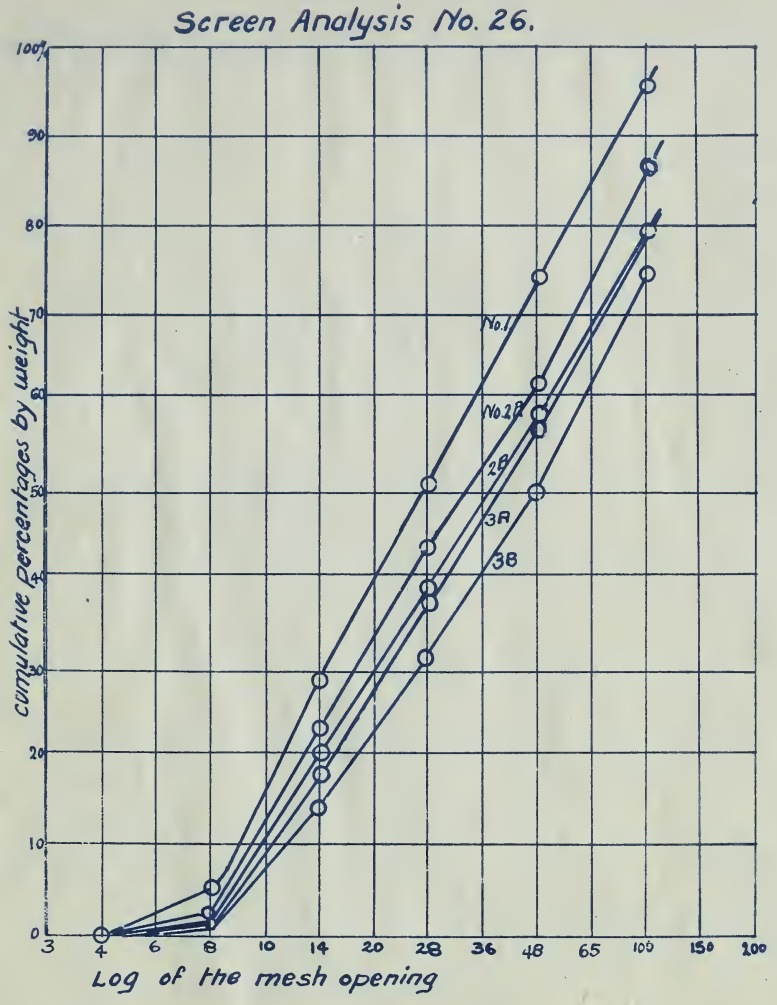
Run No.	Coal	% Ash as rec.	M.R. Binder		M.R.% Binder for ash free coal	Rattler loss	Spec. Gr Real	Spec. Gr App.	Voids %
656	C.V.C. (dirty)	53.0	5	I.B.B. (asphalt)	10.6	4.8	1.54	1.80	14.1
655	" (clean)	12.0	5	"	5.7	22.5	1.10	1.43	23.0
748	" "	12.0	6	"	6.7	5.3	1.15	1.41	18.5
749	" "	12.0	7	"	8.0	4.0	1.15	1.41	18.3
750	" "	12.0	8	"	9.1	3.7	1.17	1.40	16.5

The results of run 656 indicate that briquettes made with a high



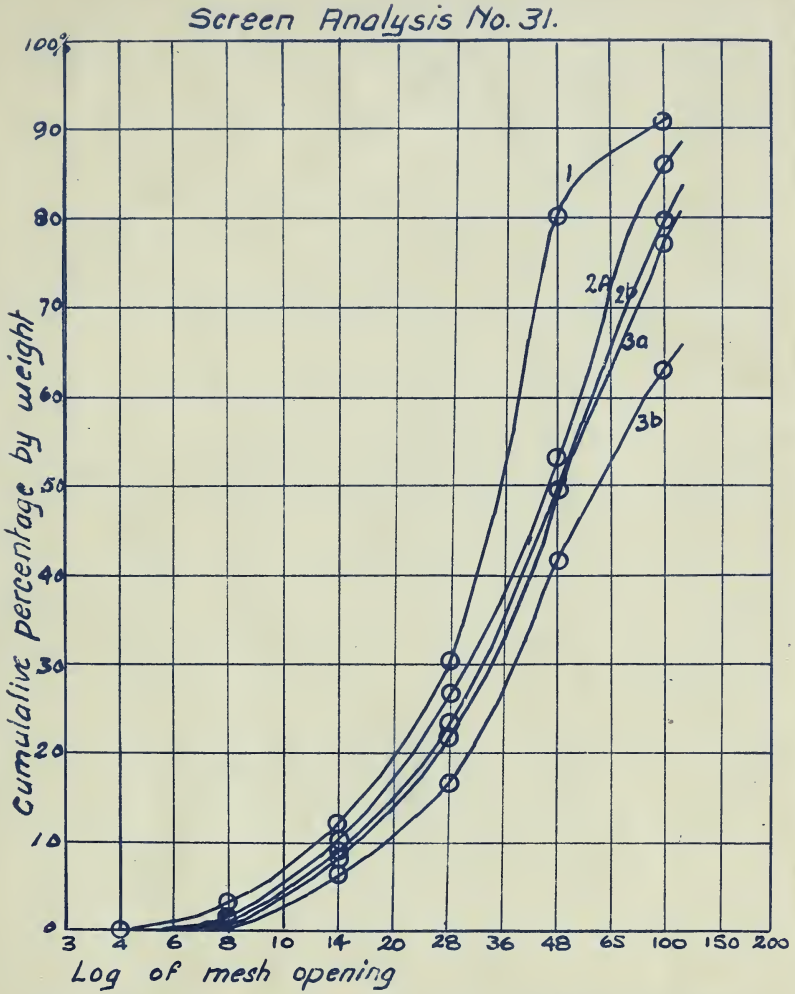
No.1. Original Sizing (C.V.Coal + Mc.G.C.Coal) + Canmore
No.2a. C.V.Coal + Mc.G.C.Coal after mixing
No.2b. C.V.Coal + Mc.G.C.Coal after pressing
No.3a. Canmore after mixing
No.3b. Canmore after pressing

FIGURE II.



No.1. Original Sizing (C.V. Coal + Mc. G.C. Coal) + Canmore
No.2a. C.V. Coal + Mc. G.C. Coal After mixing
No.2b. C.V. Coal + Mc. G.C. Coal After pressing
No.3.a. Canmore after mixing
No.3b. Canmore after pressing

FIGURE III.



No.1. Original Sizing (C.V.Coal + Mc.G.C.Coal) + Canmore
No.2b. C.V.Coal + Mc.G.C.Coal after pressing
No.2a. C.V.Coal + Mc.G.C Coal after mixing
No.3a Canmore after mixing
No.3b Canmore after pressing

FIGURE IV.

ash coal, other factors being the same, have a lower rattler loss and a higher specific gravity than those made with a low ash coal, which would indicate a better briquette. This is true so far as handling properties are concerned, and can be explained by the density of the high ash coal. But the waste of binder is easily seen when the binder is calculated to the amount required on an ash-free coal basis.

A sample of sub-bituminous slack coal was screened over Tyler Standard screens, and ash determinations run on the coal retained on screens of 4, 8, 14, 28, 48, 100, - 100 mesh. The following results indicate that the ash increases with increased fineness.

Mesh	% Ash.
+ 4	21.4
+ 8	23.6
+ 14	25.6
+ 28	26.6
+ 48	28.0
+100	28.5
-100	29.7

It was observed that briquettes made with coal high in ash always had particles of dirt present, which were not covered by the binder, and which washed out when the briquettes were exposed to the weather. The fact that the binder does not wet the dirt particles as readily as it does the coal is also borne out by work done with washing tests on coal by the Trent process. A considerable portion of the ash could be separated from the coal by this treatment, and briquettes made with coal that had been treated were better than those made by the usual procedure, with the same coal and L. R. of binder as is shown by the following results. (only the fines in each sample were washed).

Notes on Trent Process.

Briefly the Trent Process consists of adding oil, little by little, to a mixture of powdered coal and water, agitating the mass thoroughly, and of pouring off the water and dirt. This produces a partly de-ashed plastic mass called an amalgam. The process depends upon selective wetting by oil and by water, Because the coal particles are more readily wet by oil than by water, the oil displaces the thin flims of water on the surface of the coal particles. The oily coal when agitated coalesces and forms a more or less homogenous mass. The dirt particles on the other hand being more readily wet by water than by oil, separate out with the water and the dirty water can be poured off without difficulty.

The tests with the Trent Process were primarily made to study the wetting of the coal by the binder, but also to show the suitability of coals for use with the Trent Process, to see if soft coal tar pitch could be used in the process, and to find the amount of soft coal tar pitch that would be required to be used.

The work was done on McGillivray Creek bituminous coal and Sterco sub-bituminous coal. Benzole, kerosene and lubricating oil were first used and when satisfactory results were obtained, soft coal tar pitch was tried, and although some difficulties were experienced, good results were finally obtained with soft coal tar pitch. During the mixing, when soft coal tar pitch was used, the mass required to be kept at a temperature from 90° to 100°C.

Approximately 30% of soft coal tar pitch required to be added before a good amalgam was formed.

The bituminous coal, probably because it was more easily wet by oil and soft coal tar pitch, reacted more readily to this process than

did the sub-bituminous coal, giving a better amalgam and separation. Preheating the sub-bituminous coal appeared to improve the results.

To wash the coal by the Trent Process before briquetting may not be commercially feasible, because to give satisfactory results, the coal requires to be finely ground, and because too high an amount of binder would be required.

In the briquetting tests made on coal treated by this process, only the fines, approximately 25%, (which contain more than 25% of the total ash) were washed by adding the amount of binder required for the whole weight of coal. The remainder of the coal was added later and the mass briquetted in the usual way.

T A B L E V.

Trent Process - quality of Briquette.

Run No.	Coal	M.R. Binder	% R.L.
501	7760 g Sterco 240 g McG. Ck.	8 S.C.T.P.	8.8
502	8000 g. "	8 S.C.T.P.	8.7
Best results - ordinary procedure.			
481	7760 g Sterco 240 g. McG. Ck.	8 S.C.T.P.	10.9
482	" " " "	8 S.C.T.P.	10.9
492	" " " "	8 S.C.T.P.	9.2

The results in this work appear contradictory to those given in Table 4, but can be explained. The original weights of coal taken were the same and contained the same percentage of ash. The coal after treatment contained less ash, but there was also a smaller quantity of coal for the same quantity of binder because the mixing ratio of binder was calculated on the original weight of coal.

However, very little work was done with the Trent Process, because in order to give satisfactory results the coal needs to be finely ground, and this would not be desirable in briquetting.

(b) Moisture: High moisture coals are not satisfactory for briquettes unless first dried, because they disintegrate readily and will not stand firing or handling. When dried they are usually more porous and therefore require more binder.

(c) Volatile: Other conditions being equal, the quantity and nature of the volatile matter in the coal affects the amount and nature of the smoke from the briquettes.

6. Coking Properties.

A coking coal will not only require less binder, other things being equal, but will stand up much better in the fire than a non-

coking coal. This factor of non-coking can be partially overcome by the choice of a suitable binder or by the addition of some coking material.

The small retort shown in Figure 5 was obtained to test the coking properties of briquettes made with various coals and binders, to see how the briquette acted when strongly heated, and to determine the nature and amount of smoke given off during coking.

A uniform sized briquette was placed in the retort which was then placed in an electric furnace and heated to the temperature desired. By this method exact conditions could be maintained and a better comparison of the points under observation made.

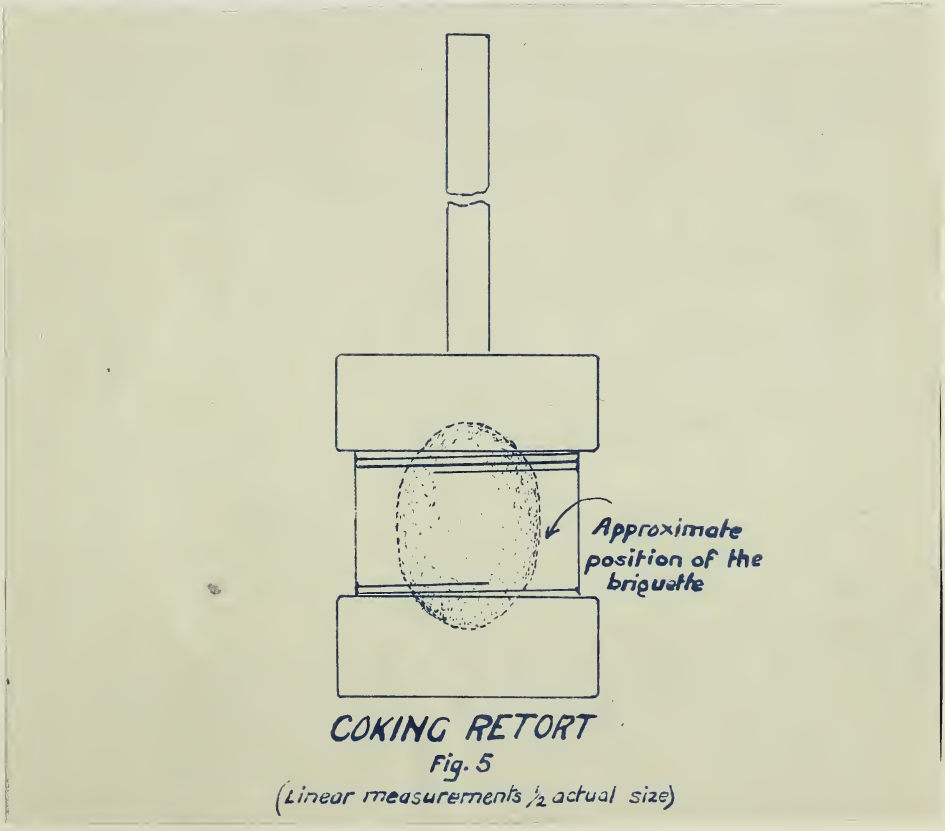


FIGURE V.

The following results were obtained in the coking tests. Briquettes made with:

(1) Canmore semi-anthracite coal coked, but the briquettes did not retain their shape. No. 2, Plate I.

(2) Greenhill bituminous coal coked. The coke was strong, which indicates good firing properties. No. 1, Plate I.

(3) Sterco sub-bituminous coal did not coke, which indicates that they will not stand up if thrown upon a hot fire. The briquettes, after the coking test, fell to pieces. No. 3, Plate I.

(4) Sterco sub-bituminous, and 6% McGillivray Creek bituminous coal coked fairly well. They retained their shape, as shown by No. 4, Plate I.

(5) Sterco sub-bituminous and 10% McGillivray Creek bituminous coal coked well and retained their shape. The coke was quite strong indicating good firing properties.

(6) Carbonized lignite - retained their shape but the briquettes were not very strong after the coking test.

Plate I shows coking properties.

7. Resistance to wetting with water.

Sub-bituminous and lignite coals wet very easily with water; semi-anthracite coal will wet, but not as readily, while bituminous coals are very difficult to wet. No specific study has been made of this property, but it has been studied indirectly in other connections and will be referred to again in the discussion on the effect of moisture in briquetting.

Since the commencement of the briquetting work 674 runs of briquettes have been made. Classified by coals these are: Semi-anthracite, (Canmore) 61; Bituminous (Greenhill) 175; Sub-bituminous, (Sterco, Saunders Creek, Foothills and Coal Valley coal) 394; Carbonized Lignite, (Carbonized lignite received from the Lignite Utilization Board of Canada and local lignites carbonized in this laboratory) 44. Good briquettes

SIDE VIEW ORIGINAL BRIQUETTE

NO.1 GREENHILL COAL

NO.2 CANMORE COAL

NO.3 STERCO COAL

NO.4 STERCO + 6 % Mc.C.C COAL

NO.5 STERCO + 10% Mc.C.C.

NO.6. CARBONIZED LIGNITE

P L A T E I.

Briquettes - Before and After Coking.

have been made with all these types.

S i z i n g o f C o a l.

The size and proportion of the particles of the material to be briquetted are of sufficient importance to warrant particular attention, because the amount of binder required depends upon the amount of surface to be covered and the number and size of the voids to be filled.

Other factors being the same, the amount of surface to be covered varies inversely with the density of the coal and the size of the particles. Thus if a coal 1.5 apparent specific gravity, requires 6% of binder by weight, one with specific gravity 1.1 will require 8.2% of binder by weight. The variation in the size of the grains has an even greater influence upon the amount of binder required. The following table taken from Bulletin #24, United States Bureau of Mines*, shows relation between the relative amount of surface to be covered in coal slack of varying degrees of fineness.

Relation between size of grain and amount of surface.

No. of Meshes to inch.	Diameter of wire in inches.	Size of mesh mms.	Relative amount of surface.
1	0.131	25.400	1
2	0.103	12,700	2
4	0.079	6.350	4
10	0.027	2.000	12.7
20	0.0165	1.000	25.4
30	0.01375	0.670	37.9
40	0.01025	0.500	50.8
50	0.00900	0.310	81.9
80	0.00575	0.230	110.0
100	0.00450	0.170	150.0
200	0.00235	0.085	300.0

The relative amount of surface area is a theoretical consideration, since it is generally accepted that: (1) Uniformity of size of

* Mills, James E. Bulletin #24, U.S.Bureau of Mines, page 17.

particles, whether of coarse or fine, give high voids; (2) Mixed sizes can be so arranged to give low voids; (3) Coarse sizes give a low surface area, but also give a briquette with a rough surface which abrades easily; (4) Fine sizes give high surface area, but a briquette with a smooth surface.

The density of the coal is an uncontrollable factor, but the amounts of each size in the mix can be controlled, although fine crushing and close adjustment of the sizes may be costly in a commercial plant.

A study of the problem of sizing was made in order to determine the sizing most suitable for use in briquetting.

No attempt was made to calculate mathematically the surface area of different screen mixtures on account of the irregular sizes and shapes of the particles.

An attempt was made, however, to determine the relative voids of different screen mixtures by filling and weighing a flask of known volume with these. This work was abandoned on account of the difficulty of getting uniform packing in each test. Methods of tapping to get uniform packing were tried, and as the coal settled, more was added. Comparative results were not obtained, although the material had been tapped for several hours. There was also a segregation of particles, the coarser material coming to the top.

It then appeared possible that the screen analysis of the coal as it occurred in a good briquette would be a guide to the optimum screen analysis of the coal for briquetting.

At this time work was being carried on to test the amount of crushing undergone by the coal during mixing and pressing. As a means of determining this, briquettes were made from a sample of coal of known screen analysis. Samples of the mix and of briquettes were taken, the binder extracted with a solvent (benzene) and screen analyses run on the coals.*

The results indicated that there was always a tendency for the material to crush to approximately the same sizing as shown in Figure 6. It was expected that if coal of this sizing were used for making briquettes, there would be much less crushing during the process. This was tried in run 492, and good results obtained. The crushing was minimized and the briquettes were the best to date with this coal and percentage of binder. It is interesting to note that the sizing of the coal in the briquettes of this run was very similar to that given in Appendix 28, Figure 8h of the First General Report of the Lignite Utilization Board of Canada*for the coal after mastication in an edge-runner at the Nukol Briquetting Plant. The high pressures in an edge-runner should rapidly crush the coal and binder to the condition of minimum voids. If there is any justification for the assumption that this is approximately the sizing with minimum voids, it would indicate that close adjustment of the sizes could be obtained commercially at reasonable cost by use of an edge-runner.

A further test was made to see if by using coal of the sizing represented in the briquettes of the last run a further improvement could be made. In this case, however, the briquettes were poorer,

* Footnote: The cumulative percentages of the amount retained on Tyler Standard Screens of 4, 8, 14, 28, 48, 100 mesh and the percentage passing 100 mesh were plotted against the log of the mesh opening on logarithmic paper.

* Lignite Utilization Board of Canada, First General Report, Fig. 8 h.

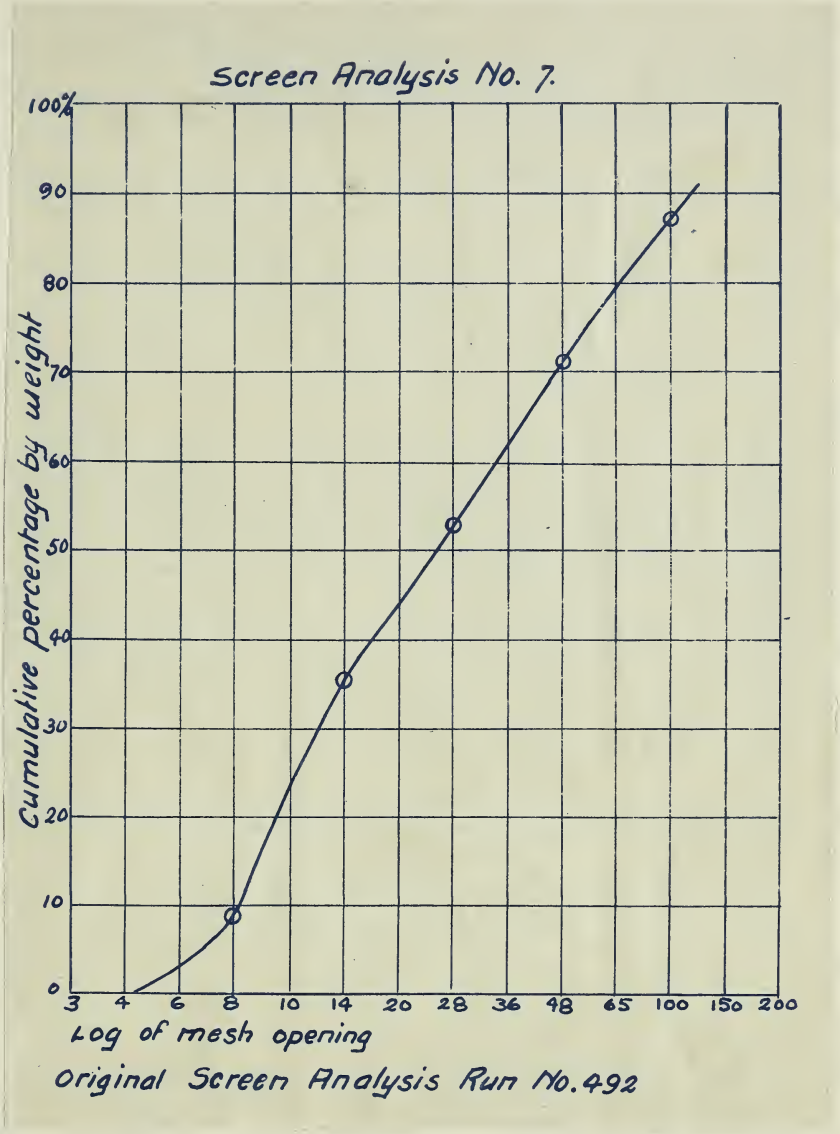

Screen Analysis No. 7.
100%
90
80
70
60
50
40
30
20
10
0
Cumulative percentage by weight
3
4
6
8
10
14
20
28
36
48
65
100
150
200
Log of mesh opening
Original Screen Analysis Run No. 492

FIGURE VI.

indicating the optimum sizing had been passed. Briquettes with several other trial variations from the optimum sizing were made. The inferior quality of these briquettes served to show the importance of the correct sizing, but it was difficult to know if the best possible sizing had been found. At this point it was decided to use the screen analysis representing the optimum sizing obtained thus far as a base-line, and to draw within certain limits on either side of it a large number of curves. Figure 7 indicates most of the possibilities have been taken into account.

Samples of coal were made up with each of these sizing and briquettes made. The tests of the briquettes gave interesting results and valuable data. The work was repeated using two mixing ratios of Imperial Briquette Binder (asphalt) and one of Soft Coal Tar Pitch.

Figure 8 gives the results obtained. In general there are three types of curves characterized by the results obtained in the tests. These are with coal of screen analysis Nos. 17, 26 and 32, the results of which are shown in Table 6 .

T A B L E 6.

Sizing of Coal and Quality of Briquette.

Run No.	No. Screen analysis.	M. R. of binder	% Rattler loss	Specific Gravity Apparent	Real	% Voids
		A. Coal Valley Sub-bituminous Coal.				
596	17	5 I.B.B. (asphalt)	9.9	1.30	1.50	13.3
605	26	"	7.2	1.29	1.51	14.1
611	32	"	51.0	1.21	1.49	19.0
580	17	6 "	5.0	1.30	1.48	12.3
589	26	"	5.0	1.29	1.48	13.0
595	32	"	21.3	1.25	1.50	16.5

ntage by weight

50 60 70 80 90 100

17
27
22
18
19
23
Base Line
24
20
29
25
30
21
26
28
31
32

Cumulative percentage by

50
40
30
20
10
0

Base 4

21

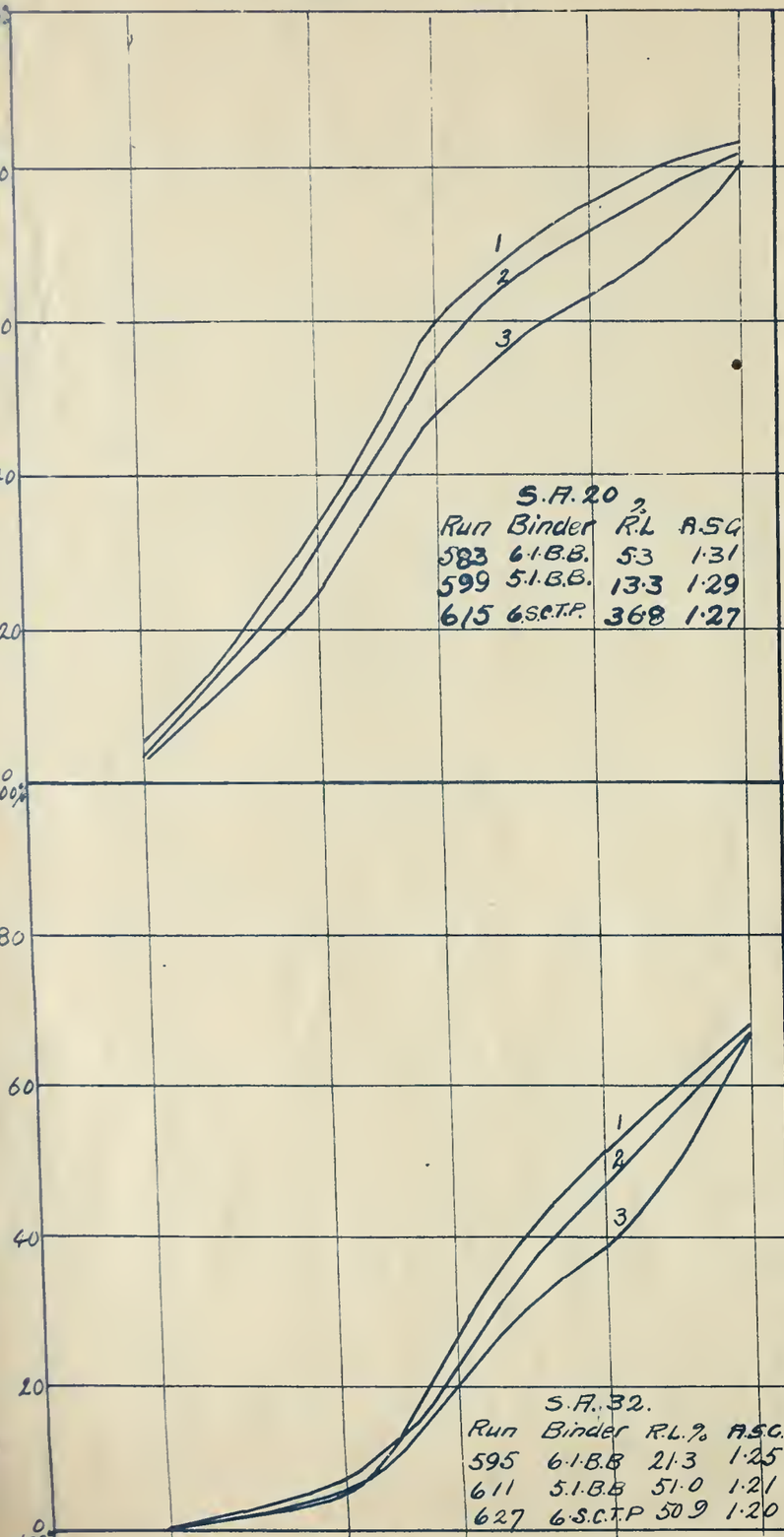
31

32

8
14
28
48
100

Log of mesh opening

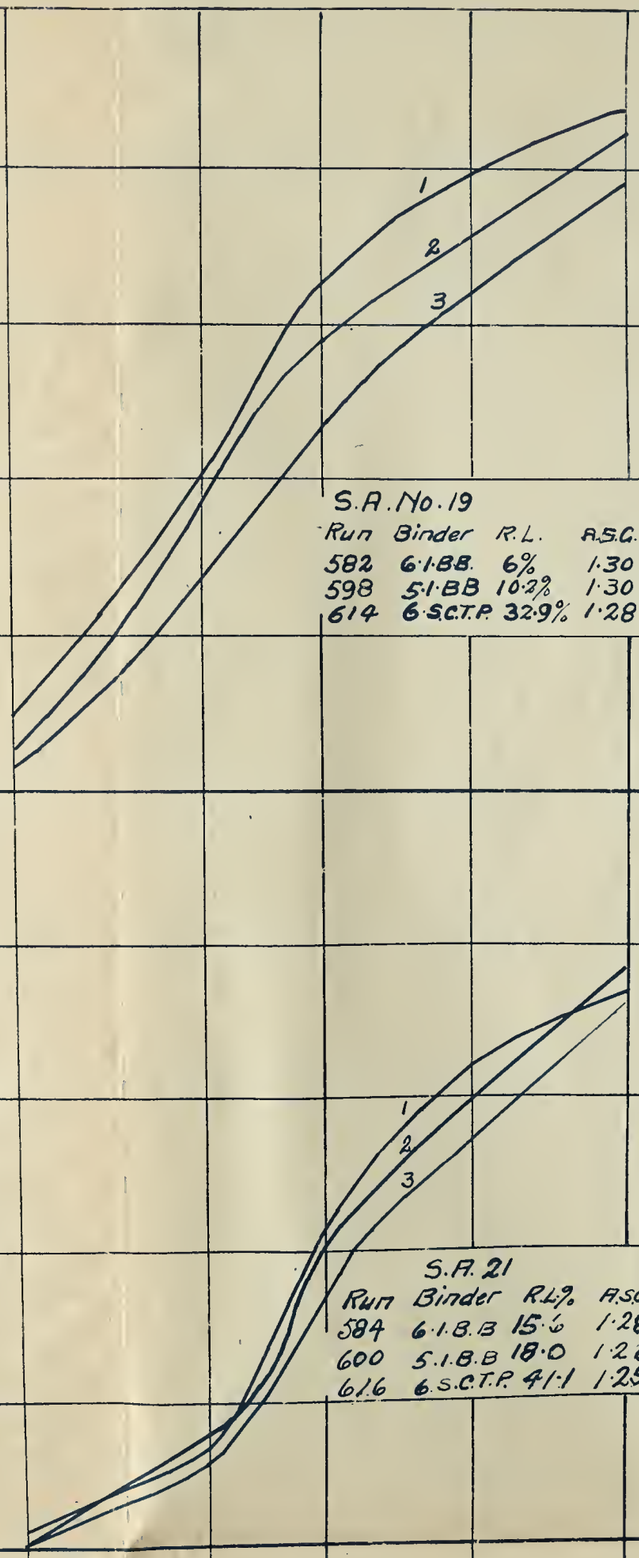
No. 1. Original Sizing



S.A. 20 2.

Run	Binder	R.L	A.S.G
583	6.1.B.B.	5.3	1.31
599	5.1.B.B.	13.3	1.29
615	6.S.C.T.P.	36.8	1.27

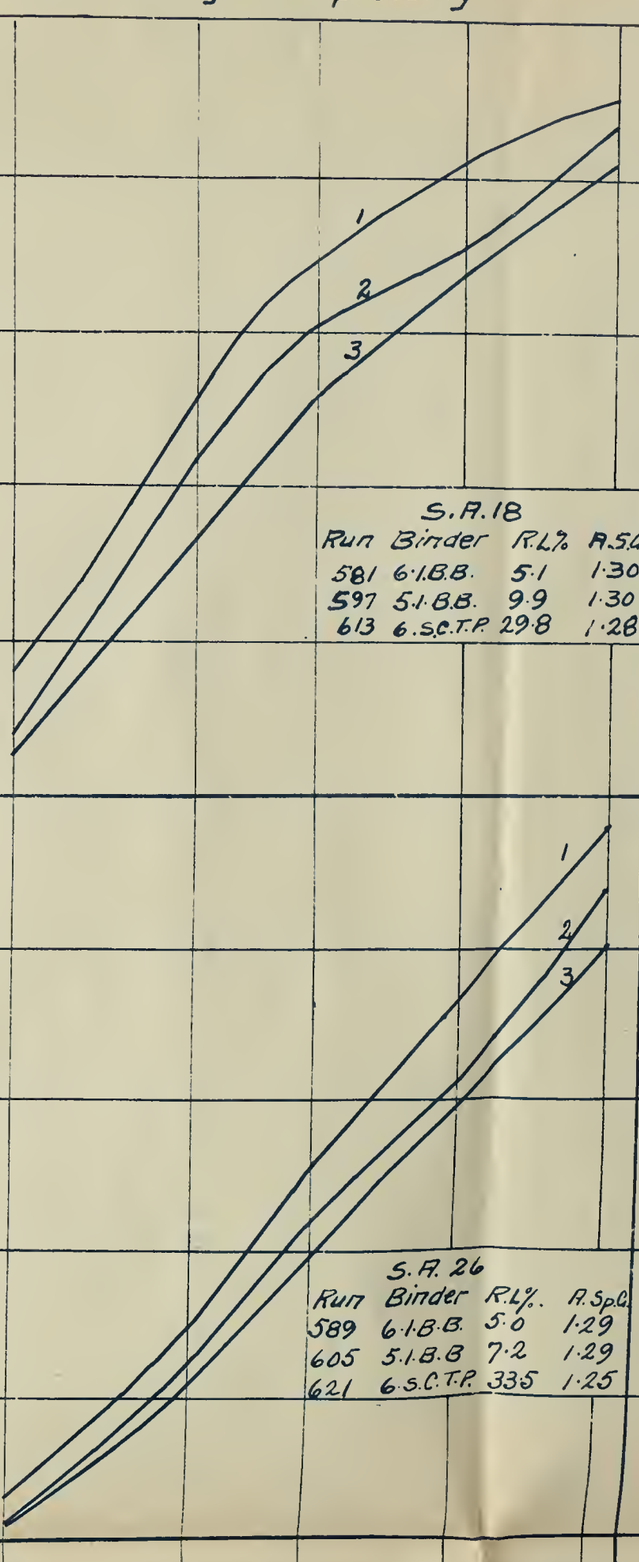
No. 2. Sizing after mixing



S.A. No. 19

Run	Binder	R.L.	A.S.G.
582	6.1.BB.	6%	1.30
598	5.1.BB	10.2%	1.30
614	6.S.C.T.P.	32.9%	1.28

No. 3. Sizing after pressing



S.A. 18

Run	Binder	R.L%	A.S.G.
581	6.1.B.B.	5.1	1.30
597	5.1.B.B.	9.9	1.30
613	6.S.C.T.P.	29.8	1.28

Percentage by weight

S.A. 32.

Run	Binder	R.L.%	A.S.G.
595	6.1.B.B	21.3	1.25
611	5.1.B.B	51.0	1.21
627	6.S.C.T.P	50.9	1.20

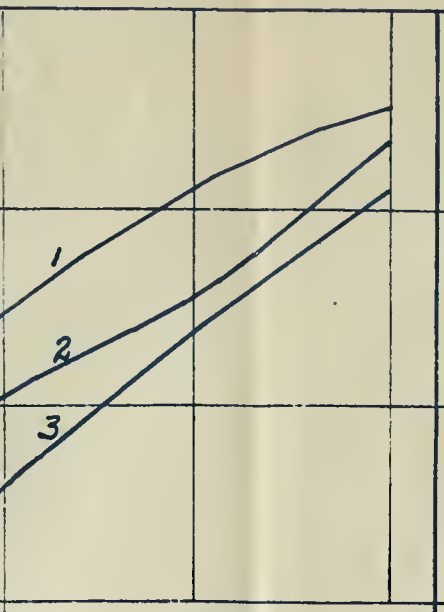
S.A. 21

Run	Binder	R.L%	A.S.G.
584	6.1.B.B	15.6	1.28
600	5.1.B.B	18.0	1.26
616	6.S.C.T.P.	41.1	1.25

S.A. 26

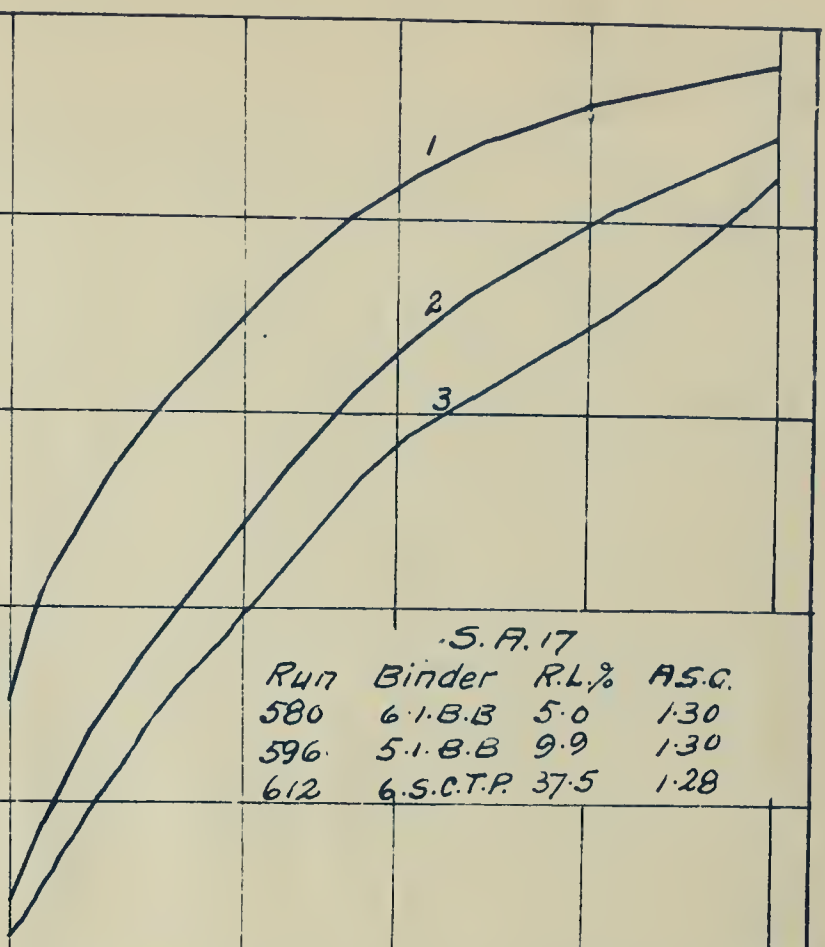
Run	Binder	R.L%.	A.Sp.G.
589	6.1.B.B.	5.0	1.29
605	5.1.B.B	7.2	1.29
621	6.S.C.T.P.	33.5	1.25

pressing



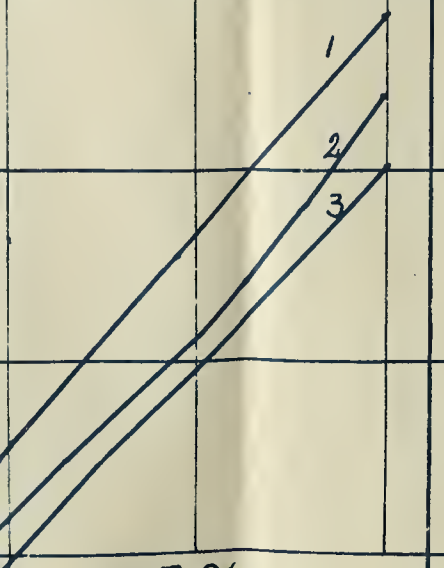
S.A. 18

Run	Binder	R.L%	A.S.G.
581	6.1.B.B.	5.1	1.30
597	5.1.B.B.	9.9	1.30
613	6.S.C.T.P.	29.8	1.28



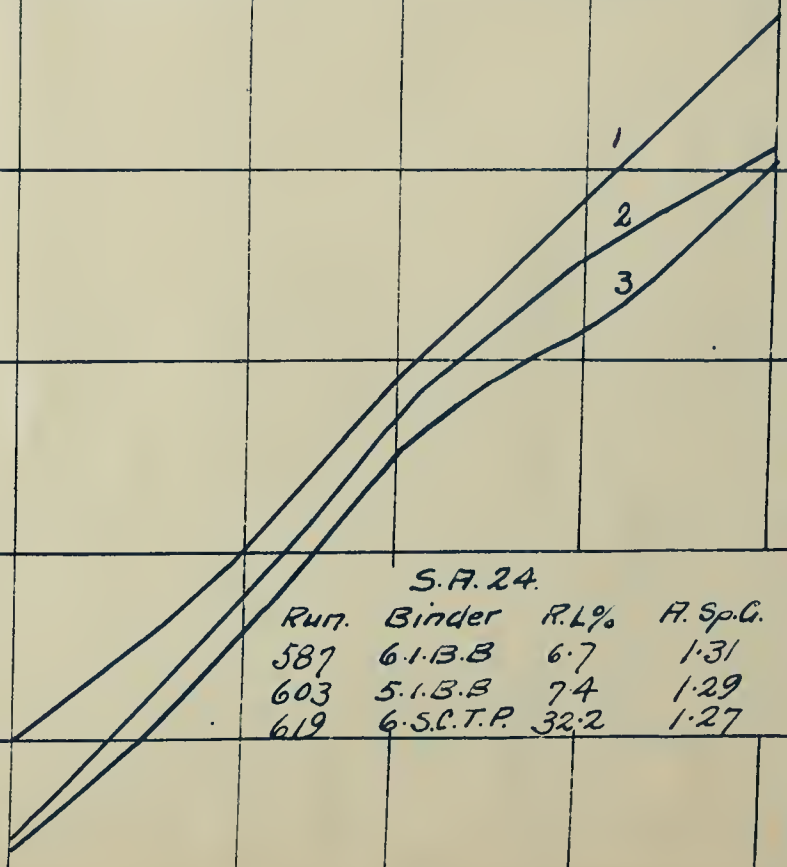
S.A. 17

Run	Binder	R.L.%	A.S.G.
580	6.1.B.B	5.0	1.30
596	5.1.B.B	9.9	1.30
612	6.S.C.T.P.	37.5	1.28



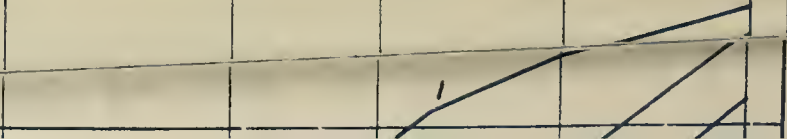
S.A. 26

Run	Binder	R.L%.	A.Sp.G.
589	6.1.B.B.	5.0	1.29
605	5.1.B.B	7.2	1.29
621	6.S.C.T.P.	33.5	1.25



S.A. 24.

Run.	Binder	R.L%	A. Sp.G.
587	6.1.B.B	6.7	1.31
603	5.1.B.B	7.4	1.29
619	6.S.C.T.P.	32.2	1.27



Cumulative percentage by

Run	Binder	R.L.%	A.S.C.
595	6.1.B.B	21.3	1.25
611	5.1.B.B	51.0	1.21
627	6.S.C.T.P	50.9	1.20

S.A.28

Run	Binder	R.L.%	A.S.C.
591	6.1.B.B.	4.1	1.30
607	5.1.B.B	9.1	1.26
623	6.S.C.T.P.	36.8	1.24

S.A.29

Run	Binder	R.L.%	A.Sp.G
592	6.1.B.B	5.8	1.31
608	5.1.B.B	9.6	1.28
624	6.S.C.T.P	38.5	1.25

S.A.31

Run.	Binder	R.L.%	A.S.G.
594	6.1.B.B	4.6	1.27
610	5.1.B.B	7.2	1.22
626	6.S.C.T.P	37.9	1.19

S.A.23

Run	Binder	R.L.%	A.S.G
586	6.1.B.B	5.3	1.31
602	5.1.B.B	13.3	1.29
618	6.S.C.T.P	41.1	1.27

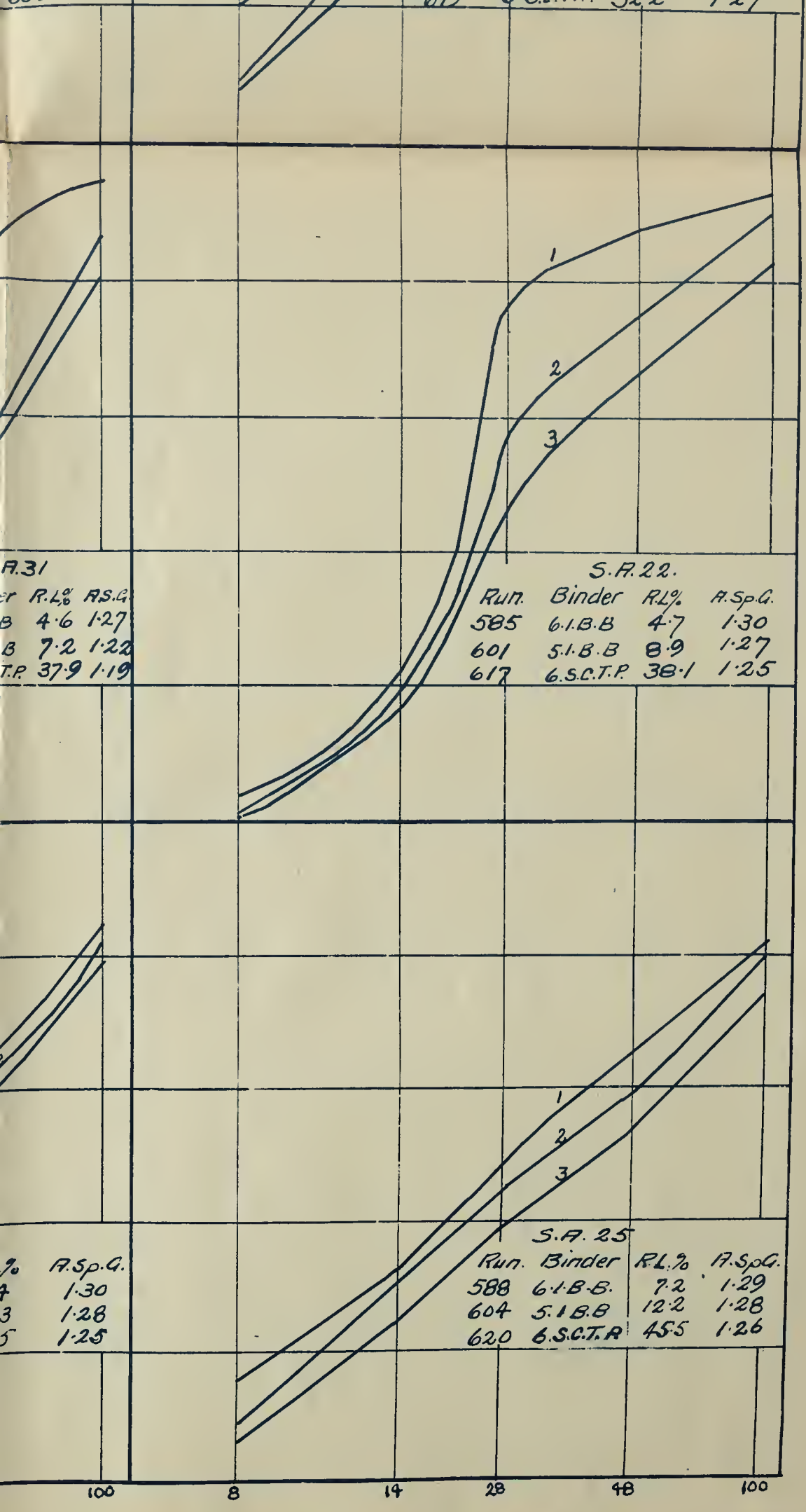
S.A.27

Run	Binder	R.L.%	A.Sp.G.
590	6.1.B.B	7.5	1.32
606	5.1.B.B	9.9	1.30
622	6.S.C.T.P.	39.4	1.28

S.A.30

Run	Binder	R.L.%	A.Sp.G.
593	6.1.B.B	5.4	1.30
609	5.1.B.B.	12.3	1.28
625	6.S.C.T.P.	39.5	1.25

Log of mesh opening


1
2
3
S.A.22.
Run. Binder R.L% A.Sp.G.
585 6.1.B.B 4·7 1·30
601 5.1.B.B 8·9 1·27
617 6.S.C.T.P. 38·1 1·25
S.A.31
er R.L% A.S.G.
B 4·6 1·27
B 7·2 1·22
T.P. 37·9 1·19
1
2
3
S.A. 25
Run. Binder R.L.% A.Sp.G.
588 6.1.B.B. 7·2 1·29
604 5.1.B.B 12·2 1·28
620 6.S.C.T.A 45·5 1·26
% A.Sp.G.
4 1·30
3 1·28
5 1·25
100
8
14
28
48
100

T A B L E 6 - continued.

Run.No	No. Screen analysis	L.R. of binder	% Rattler loss	Specific Gravity Apparent	Specific Gravity Real	% Voids
		A. Coal Valley Sub-bituminous Coal - continued.				
612	17	6 S.C.T.P.	37.5	1.28	1.50	15.0
621	26	"	33.5	1.25	1.51	17.4
627	32	"	50.9	1.20	1.51	20.4
		B. Canmore Semi-anthracite Coal.				
663	17	6 I.B.B. (asphalt)	5.9	1.17	1.33	12.1
661	26	"	3.1	1.15	1.33	13.1
662	31	"	7.5	1.12	1.33	15.9

Coal sized such that the screen analysis approached a straight line when plotted as is S.A. 26, Figure 8, gave briquettes with medium density, but which had a low rattler loss.

Coal sized such that the screen analysis when plotted on logarithmic paper formed a convex curve as typified by S.A. #17, Figure 8, gave briquettes with high density and medium rattler loss. The higher rattler loss may be accounted for by the amount of crushing during mixing and pressing.

Coals sized to represent a screen analysis similar to #32 which had a concave curve when plotted as in Figure 8, gave briquettes with low density and high rattler loss.

The area between the curves indicates the amount of crushing undergone by the coal during mixing and pressing. When there was a large percentage of any one size present, especially the larger sizes, there was a large amount of crushing as shown by S. A. #17, 31, 22, etc. Figure 8. There was very little crushing when the sizes were approximately the same as is shown by S. A. #26, 25, 24, etc. Figure 8. The effect of the amount of fines present is also shown by a comparison

of S. A. Nos. 25 and 26. Although the curves are very similar, the briquettes made with S. A. #25 were much poorer because of increased amount of fines present.

The above work was done on Sterco sub-bituminous coal. It was repeated in order to study the effect of sizing on a coal with widely differing properties. A very friable semi-anthracite coal from Canmore was chosen. Tests were made with three typical Screen analyses, Nos. 17, 26 and 31. (Screen analysis #31 was used instead of #32 because, due to the preponderance of fines present in #32, it always gave poor results). The results shown in Figures 2, 3 and 4, and Table 6 B indicate that although considerably more crushing takes place during mixing and pressing, the same general conclusions hold true.

B i n d e r.

(1) Definition; The term binder is applied to any substance that possesses cohesive properties and is, therefore, capable of binding fine particles together. The application of pressure, and commonly of heat, greatly assist in compacting the material.

(2) Requirements: The following are the requirements of a binder:

1. It must be sufficiently cheap to make the manufacture of briquettes profitable.
2. It must produce a strong but not brittle briquette.
3. It must produce a briquette sufficiently water-proof to withstand weather conditions.
4. It must hold the briquette together satisfactorily in fire.
5. It should not cause smoky, oily, foul-smelling or corrosive gases.
6. It should not increase the ash or clinker.
7. It should increase rather than diminish the calorific value of the fuel.

(3) Classification: A large number of organic and inorganic substances have at various times been suggested and used as binders, but

comparatively few have been a success commercially. The former, being combustible, are commonly preferred to the latter, which necessarily adds ash to the fuel. The binders used to date in the work are classified as follows: (The number of runs of briquettes made with each is given): Soft Coal Tar Pitch, 265; Hard Coal Tar Pitch, 17; Lignite Pitch, 18; Asphalts, 204; and miscellaneous mixed binders, 170.

The miscellaneous binders include the following. These have been used either alone or in combination with others, or mixed with either pitch or asphalt.

Inorganic	1.	Waterglass.	
	2.	Bentonite.	
Organic	1.	Sulphite Liquor	a. Sulphite liquor
			b. Gluterin.
			c. Lignone.
	2.	Starchy materials	a. Flour
			b. Starch
			c. Potatoes
			d. Oats and Oatmeal
	3.	Cellulose Products	a. Straw
			b. Sawdust
			c. Cathulls.

Coal Tar Pitch. Coal Tar Pitch is used extensively in Europe as a binder, but has not found favor to any extent in America. It is obtained by the distillation of coal tar from by-product coke-ovens and illuminating gas plants. Pitch of varying hardness can be obtained depending upon the amount of lighter oils that have been driven off during the distillation. The procedure in adding the coal tar pitches varies with the hardness, as soft coal tar pitch is added molten, while hard coal tar pitch can be crushed and added cold.

Coal tar pitches coke better than asphalts which makes them desirable as a binder with non-coking coals. On the other hand, they usually produce more smoke than asphalts when burning, and the smoke has an odor of creosote. When coal tar pitch was used as binder, the mix did not stick to the plungers of the press as much as when an asphalt binder was used.

Two samples of soft coal tar pitch, one with a softening point of 48.5°C and the other with a softening point of 54.0°C, and a hard coal tar pitch with a softening point of 72.6°C have been used in the experimental work here.

T A B L E V I I.

Briquettes - Soft Coal Tar Pitch.

Run No.	Coal	Mixing Ratio	% Rattler loss.	No. of runs made.
208	Greenhill	6	17.8	9
266	Greenhill	7	15.8	4
242	Saunders Creek	8	23.3	9
215	Carbonized Lignite	12	59.7	4
721	Canmore Coal	6	36.1	3
484	(7760 g Sterco & 240 g) McGillivray Ck.	6	25.0	1
469	"	7	16.2	44
492	"	8	9.2	17
728	Coal Valley Coal	6	37.8	3

Table 7 indicates that at least 7 mixing ratio of soft coal tar pitch is required to make satisfactory briquettes. The best results with this binder were obtained by adding it in a molten condition and mixing around 100°C. MacDonald's work indicated that the pressing should be done around 120°C, but the more recent work has shown that this temperature is much too high and better results can be obtained by pressing around 90°C. Briquettes made with soft coal tar pitch are hard but not brittle. They stand up well both in firing and weathering tests.

Hard Coal Tar Pitch.

T A B L E V I I I.

Briquettes - Hard Coal Tar Pitch.

Run No.	Coal	Mixing Ratio	% Rattler loss	No. of runs made.
241	Greenhill	7	18.0	1
243	Saunders Creek	8	29.6	1
223	Carbonized Lignite	14	54.5	1

Since hard coal tar pitch is brittle, briquettes made with it as binder are also brittle. Because of its higher softening point, and its more viscous nature, hard coal tar pitch requires a higher temperature of mixing and pressing than soft coal tar pitch.

The briquettes, on the whole, made with this binder have been good, but the difficulty of getting high enough temperatures of pressing has prevented more work being done with this binder.*

Lignite Pitch. Lignite pitch is the residue obtained from the distillation of the tarry materials formed during the carbonization of lignites. It differs from coal tar pitch in that it is obtained from lignites rather than bituminous coal. It is more oily in appearance and does not become brittle at ordinary temperatures. It has often been suggested that raw lignites should be carbonized and then briquetted, and in such a process the pitch obtained from the carbonizer would be available as binder in the briquetting. Extensive tests were not made here with this binder. A sample of lignite pitch received

* A difficulty experienced when pressing at high temperatures is the tendency for the mix to stick to the plungers. The only satisfactory way found to overcome this is the addition of water, but the mix cannot be pressed above 100°C if water is to be present. This appears to be too low a temperature for good results with hard coal tar pitch.

from the Lignite Utilization Board of Canada from the carbonizing plant at Bienfait, Saskatchewan, gave briquettes that were tough and that did not fracture as easily as briquettes made with coal tar pitch, but considerable trouble was experienced with the mix sticking to the plungers. This was contrary to the findings of the Lignite Utilization Board of Canada, who found that the addition of lignite pitch to the mix always lessened the tendency for the material to stick to the press. As with asphalts, the addition of steam or water before pressing overcame this difficulty. In the few tests made, it was observed that, when used with carbonized lignite, this binder caused less trouble in pressing and produced briquettes which had a better appearance than those produced with bituminous coal.

Table 9 gives the best results obtained with lignite pitch as binder.

T A B L E I X.

Briquettes - Lignite Pitch.

Run No.	Coal	Mixing Ratio	% Rattler loss.
230	Greenhill	6	18.7
238	"	7	17.9
246	Saunders Creek	8	17.8
224	Carbonized Lignite	14	23.3

Asphalt. Asphalt is the binder used in the majority of briquetting plants in America, because of:

(1) The large quantities of asphalt that are available, and its relative cost compared to other binders is lower than in European countries.

(2) It having better binding and waterproofing qualities.

(3) It being less smoky than pitches while burning.

The asphalts used as binders are chiefly obtained from the

distillation of crude asphaltic base oils. Asphalt obtained by extraction of the bitumen from bituminous sand deposits is a possible source. Natural asphalts are high in mineral matter and not desirable.

The work undertaken here was first a study of the binding qualities of asphalt and second a study of the possible sources of asphalt in Alberta.

The first tests made here with Imperial Briquette Binder gave briquettes that had a very low rattler loss, but which were not strong and could be broken by the hands. The poor results caused the work to be discontinued for some time. When the work was resumed, even though the same procedure was followed, excellent briquettes were made, and not once has there been any tendency toward soft briquettes. No satisfactory explanation for this change has been found.

T A B L E X.

Run No. Briquettes - Asphalt (Imperial Briquette Binder)

Run No.	Coal	Mixing Ratio	% Rattler loss.	Specific Gravity Apparent	Specific Gravity Real	% Voids	No. Runs
729	Greenhill	5	9.6	1.25	1.38	9.9	4
703	Canmore	4	25.9	1.16	1.34	13.7	3
719	"	5	10.4	1.18	1.33	11.5	14
659	"	6	3.1	1.17	1.33	12.4	23
559	7200 g Sterco + 800 g McG. Ck.	6	5.2	1.23	1.46	15.6	4
551	7200 Sterco + 800 g McG. Ck.	7	2.7	1.27	1.44	12.5	29
630	7200 Coal Valley 800 g McG. Ck.	5	5.3	1.25	1.49	15.9	35
591	7200 g Coal Valley 800 g McG. Ck.	6	4.1	1.30	1.49	13.1	16

Note: The best result obtained with the same coal and binder is given in the table. The number of runs made with each, under approximately the same procedure, is also included.

Table 10 indicates that the mixing ratio, by weight, of the (Imperial Briquette Binder) asphalt required is less than that of either soft or hard coal tar pitch, possibly because of its higher total bitumen content and its lower specific gravity, a mixing ratio of 5 I.B.B. giving excellent results. It should be noted that the viscosity of the asphalt decreased more slowly with rise of temperature than either the soft or hard coal tar pitch, as shown in Figure 14, P 75 and thus the temperature required for mixing must be higher.

A difficulty experienced when an asphalt binder was used was the tendency for the mix to stick to the plungers of the press. Tests were made to overcome this by adding to the binder soap or waterglass solutions. These were successful in that the mix did not adhere to the plungers, but when added, the briquettes were always of poor quality, as shown in Table No. 11.

T A B L E X I.

Addition of Waterglass.

Run No.	Coal	M. R. Binder	% Rattler Loss.
208	Greenhill	6 S.C.T.P.	17.8
209	"	6 S.C.T.P. + 25 cc. of 5% Waterglass solution	20.7
215	Carbonized Lignite	12 M.R. S.C.T.P.	59.7
212	" "	12 M.R. S.C.T.P. + 2 M.R. of 5% Waterglass solution	100.0%

On the other hand, when sufficient water is added to the mix, it can be pressed without sticking and good briquettes made.

Through the courtesy of Mr. S. M. Blair, several samples of asphalt were obtained by steam distillation of the bitumen separated from McMurray Tar Sand at the Dunvegan Separation plant, and of Wain-

wright crude oil*. These had excellent binding properties, although not quite as good as the I.B.B. (asphalt), possibly because of the higher percentage of mineral matter they contained.

Table 12 gives results of briquettes made with the above binders.

T A B L E X I I.

Briquettes - Asphalt. A. McMurray Bitumen. B. Wainwright crude oil.

Run No.	Coal	M. R. Binder	% Rattler loss	Specific Gravity Apparent	Specific Gravity Real	% Voids	No. Runs
Asphalt from - A. McMurray Bitumen, separated from McMurray Tar Sands.							
653	Canmore	5 Sample #2	23.7	1.17	1.34	12.8	4
654	"	5 Sample #3	51.5	1.16	1.34	13.5	1
668	"	6 Sample #2	16.3	1.16	1.34	13.6	3
670	"	6 Sample #3	14.5	1.17	1.34	12.9	3
675	"	6 Sample #4	12.9	1.16	1.34	13.3	3
676	"	6 Sample #5	11.6	1.17	1.34	12.7	2
Asphalt from - B - Wainwright crude oil.							
652	"	5 Sample #1	21.2	1.17	1.34	12.9	1
681	"	6 Sample #1	13.7	1.17	1.33	11.8	2
684	"	6 Sample #2	29.3	1.16	1.33	13.1	2

Asphalts for binders should be available in Alberta in large quantities at reasonable cost when commercially developed, either from the bitumen separated from the McMurray tar sands or from asphaltic base crude oils.

Waterglass. Only a few tests were made with waterglass alone as binder, because of its solubility in water. Considerable work was done, however, using solutions of waterglass in combination with pitch and asphalt. This mixture always gave a tough leathery binder which did not adhere to the plungers. It was expected that this binder, because of its nature, would give excellent results, but briquettes made from it

* The following are the penetrations in tenths of mms. of these binders, made according to the A.S.T.M. standard method D5-21, A.S.T.M. Standards, 1921 P. 728. Asphalt from McMurray Bitumen; sample #2=33; sample #3 = 17, sample #4= 36, sample #5=16. Asphalt from Wainwright Crude Oil, sample #1=37. (For comparison penetration I.B.B. Asphalt=23).

were always poor. A reason suggested for the poor quality of the briquettes is that just as the binder did not adhere to the plungers, it did not adhere to the coal particles. See Table 11.

Bentonite. Bentonite as a binder is undesirable because it is not waterproof, and because it also adds ash to the fuel. The addition of bentonite to pitch or asphalt always had a deleterious effect upon the quality of the binder, and briquettes made with a binder to which bentonite had been added were always poor.

Sulphite pitch. Sulphite pitch obtained by the evaporation of sulphite liquor has a possibility of becoming a commercial binder, although in Alberta the cost would be prohibitive, because there are no paper mills closer than the Pacific coast. The disposal of sulphite liquor is a serious problem and if some use could be made of it, large quantities would be available. Briquettes made with sulphite pitch require a heat treatment.

T A B L E X I I I.

Briquettes - Sulphite Pitch.

Run No.	Coal	M. R. Binder.	% Rattler loss.
276	Greenhill	7 Gluterin	100
277	"	10 "	45.7
258	Saunders Creek	10 Lignone	59.5

Starchy Materials. The work indicates that a large number of starchy materials are suitable as binders, but the two which give most promise are starch and flour. They are added either as a paste or dry, and formed into a paste by the addition of water and heat. Briquettes made with these binders can be pressed without difficulty, are hard, less smoky than briquettes made with bituminous binder and hold together

well in the fire, but they are not waterproof and will not stand to be stored in a damp place or exposed to the weather. Bituminous material is often added to waterproof briquettes made with these binders. Very promising results have been obtained recently by the use of flour and crude McMurray bitumen as binder. More work is required before the value of this binder is determined, because considerable trouble was experienced in pressing, which is unusual with a flour binder. The Hite binder, which is approximately one part starch, two parts asphalt and twelve parts water, is used commercially. It is claimed to have high binding properties. Briquettes made with flour or starch binders require a heat treatment, (~~Table 14,~~ in order to drive off the moisture present.

T A B L E X I V.

Briquettes - Starchy materials.

Run No.	Coal	Mixing Ratio Binder	% R.L.	Specific Gravity Apparent	Specific Gravity Real	Voids %
517	7760 g Sterco 240 g. McG. Ck.	1½ Flour 6 S.C.T.P.	9.4	1.28		
519	"	"	8.1			
708	Greenhill	1½ Flour 4 Crude McM. bitumen	2.9	1.25	1.42	11.9
709	"	1½ Flour 6 Crude McM. bitumen	2.8	1.26	1.40	9.6
736	Coal Valley	1½ Flour 6 Crude McM. A.	1.4	1.26	1.46	13.9
737	"	"	2.3	1.25	1.46	14.9
291	Saunders Creek	1½ Starch 6 S.C.T.P.	7.5			
292	"	"	5.9			

Cellulose Materials. Straw, sawdust, oathulls, etc. were tried as binders and were found to have binding properties. They first require to

Footnote: Compare the results given in the above table with those given in Table 7, page 29.

be converted to a jelly-like mass before use. This can be done in several ways, but most readily by cooking with a dilute solution of caustic soda in an autoclave and then pulping in a ballmill. The fibres of the straw and wood, as such, appear to be valueless as the more completely these are pulped, the better the result. The fibre may be valuable as a filler with porous materials. The temperature of cooking can be varied over a considerable range, but 180°C gives rapid treatment without charring of the material. Briquettes made with these binders are not waterproof, and unless some waterproofing agent is added they will not stand weathering. Some English experimenters recently claim to have perfected a straw binder which satisfies the binder requirements. They use a fermentation process in place of the caustic soda treatment for softening the straw. The success they have attained indicates that further investigation here might be advantageous because of the quantities of waste straw annually available in Alberta.

T A B L E X V.

Typical results Briquettes - Cellulose Materials.

Run No.	Coal	Mixing Ratio Binder	Rattler loss %	Specific Gravity Apparent	Specific Gravity Real	Voids %
496	7760 G Sterco 240 g McG. Gk.	1.38 Straw, 6 S.C.T.P.	14.2	1.24		
497	"	1.6 Straw, 0.2 NaOH & 6 S.C.T.P.	7.6	1.25		
498	"	1.6 Straw + 0.1 H_2SO_4 + 6 S.C.T.P.	13.5	1.22		
384	Sterco	1 Crushed oats, 6 S.C.T.P.	8.9	1.31		
382	"	1½ " " 6 S.C.T.P.	7.4	1.30		
383	"	1½ " " 6 S.C.T.P.	6.9	1.31		
385	"	2 " " 6 S.C.T.P.	5.7	1.30		

Footnote: Compare the results given in Table 15 with those given in Table 7, page 29.

T A B L E X V - continued.

Run No.	Coal	Mixing Ratio Binder	Rattler loss %	Specific Gravity Apparent	Real	Voids %
365	Sterco	2 Sawdust, 6 S.C.T.P.	13.5	1.28		
367	"	2 " 6 S.C.T.P.	12.8	1.31		
380	"	2 " 6 S.C.T.P.	14.5	1.30		
329	Sterco	1.05 Sawdust, 1.05 NaOH + 6 S.C.T.P.	14.0	1.33		
330	"	1.2 Sawdust + 0.8 NaOH + 6 S.C.T.P.	9.8	1.31		
331	"	1.6 Sawdust + 4 NaOH + 6 S.C.T.P.	6.4	1.32		

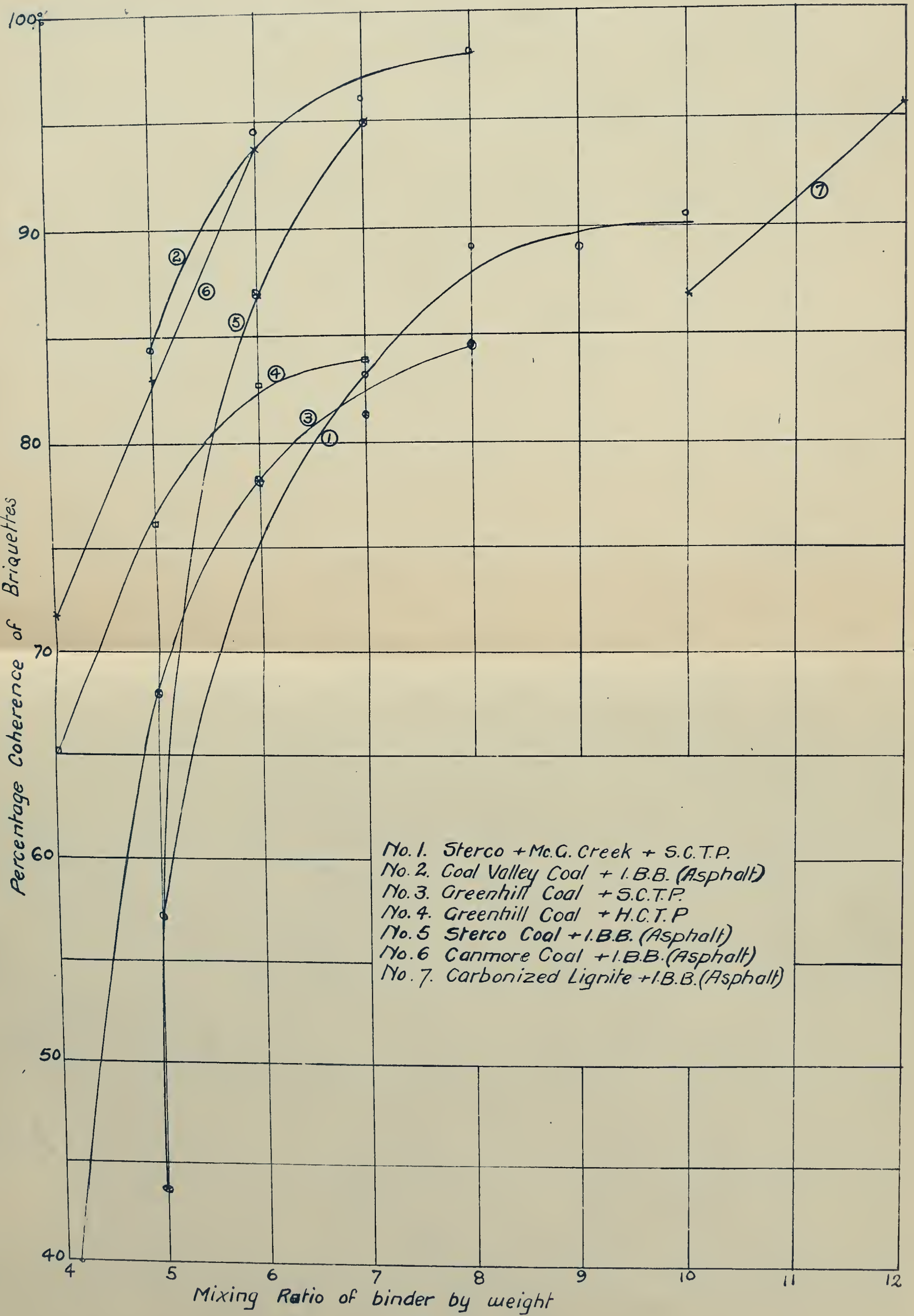
Quantity of Binder. It is generally accepted that the coherence of briquettes increases slowly at first with increase in the amount of binder. When sufficient has been added to coat the particles of coal, there is a rapid increase in coherence until the interstices are filled, when the increase again becomes gradual. Figure 9 indicates the results obtained with various coals and binders during the period of rapid increase in coherence (on account of increased M. R. of binder).

The coherence of briquettes made with any mixing ratio of a binder has already been shown to vary with the nature and sizing of the coal, and the method of procedure. Tests have been made from time to time to find the minimum amount of binder required to make good briquettes with different coals and binders under optimum conditions. Table 16 shows the best results obtained with different coals when the mixing ratio of binder was varied.

T A B L E X V I.

Briquettes - Varying Mixing Ratio of Binder.

Run No.	Mixing Ratio Binder	% Rattler loss	Specific Gravity Apparent	Real	Voids %	No. of Runs
	Canmore Coal.					
703	4 I.B.B. (asphalt)	25.9	1.16	1.34	13.7	3
719	5 " "	10.4	1.18	1.33	11.5	14
659	6 " "	3.1	1.17	1.33	12.4	23


100%
90
80
70
60
50
40
Percentage Coherence of Briquettes
4
5
6
7
8
9
10
11
12
Mixing Ratio of binder by weight
No. 1. Sterco + Mc.G. Creek + S.C.T.P.
No. 2. Coal Valley Coal + I.B.B. (Asphalt)
No. 3. Greenhill Coal + S.C.T.P.
No. 4. Greenhill Coal + H.C.T.P
No. 5 Sterco Coal + I.B.B. (Asphalt)
No. 6 Canmore Coal + I.B.B. (Asphalt)
No. 7. Carbonized Lignite + I.B.B. (Asphalt)
①
②
③
④
⑤
⑥
⑦

T A B L E X V I - continued.

Run No.	Mixing Ratio Binder	% Rattler loss	Specific Gravity Apparent	Specific Gravity Real	Voids %	No. of Runs
	Coal Valley Coal.					
747	5 I.B.B (Asphalt)	15.4	1.13	1.41	19.9	1
748	6 " "	5.3	1.15	1.41	18.5	1
749	7 " "	4.0	1.15	1.41	18.3	1
750	8 " "	1.9	1.17	1.40	16.5	1
	7200 g. Sterco and 800 g. McGillivray Creek Coal					
559	6 I.B.B. (asphalt)	5.2	1.23	1.46	15.6	4
551	7 " "	2.7	1.27	1.44	12.5	29
484	6 S.C.T.P.	25.0	---	---	---	1
469	7 S.C.T.P.	16.2	---	---	---	44
492	8 S.C.T.P.	9.2	1.28	---	---	17

Table 17 gives the best results obtained when Imperial Briquette Binder (asphalt) was used with various coals. Similar results have been obtained with other binders.

T A B L E X V I I.

Run	Coal	% Rattler loss	Specific Gravity Apparent	Specific Gravity Real	Voids %	No. of Runs
	5 Mixing Ratio, I.B.B. (asphalt)					
719	Canmore	10.4	1.18	1.33	11.5	14
729	Greenhill	9.6	1.25	1.38	9.9	4
630	7200 g. Sterco + 800 g. McG. Ck.	5.3	1.25	1.49	15.9	35
723	Washed Coal Valley	8.5	1.22	1.47	17.2	8
	6 Mixing Ratio I.B.B. (asphalt)					
659	Canmore	3.1	1.17	1.33	12.4	23
559	7200g. Sterco + 800 g. McG. Ck.	5.2	1.23	1.46	15.6	4
591	7200 g. Coal Valley + 800 g. McG. Ck.	4.1	1.30	1.50	13.1	16
686	Washed Coal Valley	6.5	1.23	1.48	16.6	4

No comparison of the results obtained with different coals and binders can be given until a large number of runs have been made with each to determine the optimum conditions for the briquetting of such a mix. Table 18, which gives the results of a series of briquettes made with

the same coal and mixing ratio of binder under varying conditions of sizing, temperature of mixing, temperature of pressing, and the temperature of the laboratory when the rattler test was made, clearly shows the importance of determining the optimum conditions. The optimum conditions for one binder and coal may not be suitable for use with a coal or binder which has widely different properties.

T A B L E X V I I I.

Briquettes - Determination of Optimum procedure.
7200 g. Coal Valley Coal, 800 g. McGillivray Creek Coal and 5 Mixing Ratio Imperial Briquette Binder.

Run	S.A.	Temp* Coal	Temp. Mix.	Temp. Press.	% Moist.	% R. L.	Specific Gravity Apparent	Specific Gravity Real	Voids %
Varying sizing of coal.									
596	17	100	107	93	3.6	9.9	1.30	1.50	13.3
597	18	100	110	92	4.1	9.9	1.30	1.50	13.3
598	19	100	109	93	3.5	10.2	1.30	1.50	13.7
599	20	100	106	93	3.6	11.3	1.29	1.50	14.5
600	21	100	109	92	2.3	18.0	1.26	1.50	16.5
601	22	100	108	92	3.1	8.9	1.27	1.50	15.2
602	23	104	105	92	3.3	13.3	1.29	1.50	14.2
603	24	100	114	93	3.3	7.4	1.29	1.50	14.5
604	25	100	114	93	4.0	12.2	1.28	1.49	14.1
605	26	100	112	92	3.6	7.2	1.29	1.51	14.1
606	27	100	111	94	3.9	9.9	1.30	1.51	13.8
607	28	100	111	93	3.4	9.1	1.26	1.50	15.7
608	29	100	109	92	3.6	9.6	1.28	1.49	14.5
609	30	100	112	93	3.6	12.3	1.28	1.49	14.4
610	31	101	111	94	3.2	7.2	1.22	1.48	17.4
611	32	100	112	93	2.9	51.0	1.21	1.49	19.0
Varying Temperature Mixing.									
630	26	110	116	94	5.0	5.3	1.25	1.49	15.9
631	26	110	116	95	5.3	6.9	1.24	1.49	17.2
632	26	87	103	94	6.9	7.4	1.25	1.49	16.5
633	26	75	97	94	7.2	8.9	1.24	1.49	17.2
c634	26	with coal	97	90	7.3	8.5	1.25	1.49	16.7
635	26	"	92	95	6.9	10.8	1.24	1.49	16.8
636	26	"	79	88	7.8	29.0	1.25	1.49	16.6
637	26	"	63	64	7.2	87.4	1.24	1.49	17.0

* Temperature of the coal when the binder was added.
c The molten binder was placed in the mixer at the same time as the coal, which was at the temperature of the laboratory.

T A B L E X V I I I - continued.

Varying Temperatures of Pressing.

Run	S.A.	Temp. Coal	Temp. Mix.	Temp. Press.	% Moist.	% R.L.	Specific Gravity Apparent	Specific Gravity Real	Voids %
643	26	100	105	94	5.7	10.1	1.24	1.50	16.9
644	26	100	107	75	7.4	10.5	1.23	1.49	17.2
645	26	100	107	85	4.9	14.6	1.23	1.49	17.9
646	26	100	109	65	5.1	30.0	1.22	1.49	18.7
647	26	100	105	58	6.6	11.7	1.25	1.49	16.0
Varying Temperatures at which Rattler Test made*									
						A.M.	P.M.		
638	26	90	104	92	7.3	16.1	9.0	1.24	1.49	17.3
639	26	70	90	91	6.6	12.1	8.5	1.25	1.49	16.2
640	26	110	125	93	4.5	12.6	8.7	1.23	1.48	16.6
641	26	106	132	94	4.5	14.5	7.7	1.22	1.49	18.5
642	26	109	120	93	4.5	12.6	8.3	1.23	1.50	18.0

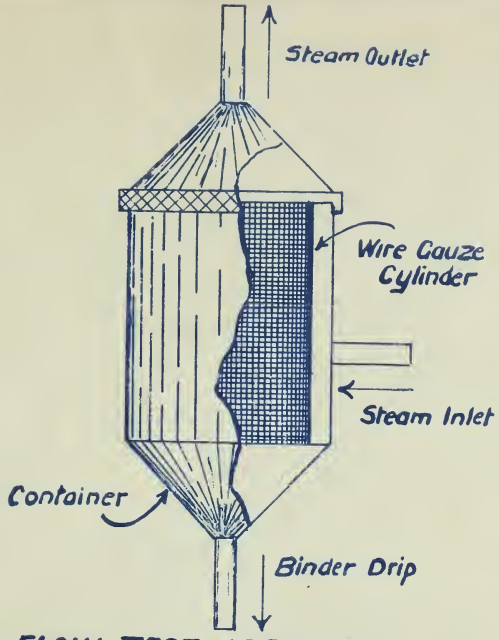
Flow Test. The flow test was devised in an attempt to measure the quantity of different binders that would naturally adhere to different coals at various temperatures and to test what effect the addition of steam, water, waterglass, or soap solutions would have upon this amount. It was felt that the results of these tests would give valuable information which could be applied in briquetting.

The apparatus consisted of a wire gauze cylinder supported in a container, as shown by Figure 10. The method adopted was to fill the cylinder with a determined weight or volume of coal of a definite size and immerse the whole in molten binder until all the particles of the coal were thoroughly covered. The binder was then allowed to cool to about 80°C, when the cylinder was removed and placed in the container. The container was then placed in an oven at a definite temperature and the excess binder allowed to drain off. This was repeated at successive higher temperatures, and the weight of binder adhering to the coal at

* In runs 638-642 inclusive, a rattler test was made in the morning when the temperature of the laboratory was about 15 °C. The test was repeated in the afternoon when the temperature of laboratory was about 22°C.

Footnote - Page 43 (continued).

The results obtained in runs 638 - 642 showed, what had not previously been suspected, that the temperature at which the rattler tests are made is a very important factor. Neglect to control the temperature during the rattler tests may account for some of the erratic results that have been obtained from time to time. Plans were then made to test the effect of this factor over a range of temperatures, when using different binders, but this has not been done to date, because climatic conditions have not been suitable. However, in order to keep this factor constant in all subsequent runs, the temperature of the laboratory was kept at about 22°C when the rattler tests were being made.



FLOW TEST APPARATUS

Fig. 10

(Linear measurements ½ actual size)

F I G U R E X.

each temperature determined. These quantities were recorded as so many parts of binder per hundred parts of coal, by weight or by volume.*

To determine the effect of water, waterglass, or soap solutions, the desired quantities of each were added to the binder and the determinations made by the above method. A difficulty present is that at the higher temperatures part of the water evaporates and no measure of the amount present can be determined.

When the effect of steam was determined, the same procedure was followed except that steam at the same temperature as the oven was passed into the container through the side tube and allowed to escape through the tube at the top, open to the room.

The above tests were repeated with different coals and different binders, but the work is in the experimental stage and some changes ~~in~~

* This amount termed Natural Mixing Ratio.

in procedure require to be made before definite results can be given.

The tests to date indicate the following:

(1) The natural mixing ratio depends upon the type of coal used, the following order being taken; bituminous, sub-bituminous, moisture-free lignite and carbonized lignite.

(2) The mixing ratio by volume is less than the mixing ratio by weight. This was shown to a marked degree by the tests made on carbonized lignite. It was expected that with this material the mixing ratio by volume would be very high, because of its porosity; a possible explanation for the low result is that only the surface is being wet by the binder.

(3) The natural mixing ratio decreases rapidly with increase in temperature in all cases except where carbonized lignite was used. When it was used the decrease was gradual, but a possible explanation for this is that more of the binder was seeping into the pores at the higher temperatures.

(4) The addition of water, waterglass or soap solutions materially increases the natural mixing ratio of the binder at all temperatures, This may be the result of a more complete covering of the particles caused by the frothing of the binder.

(5) When steam is passed through the apparatus, the percentage of binder remaining on the coal is decreased.

F a c to o r s Influencing Mixing & Pressing.

(1) Time of Mixing. N.H.Atkinson found when using Greenhill coal and soft coal tar pitch that 2-3 minutes (after the binder had been added) was sufficient time to give thorough mixing, when the temperature of the mix was at least 25°C above the softening point of the binder. It was felt that the hardness of the coal might influence this factor and tests were made to determine the effect of prolonged mixing on the following coals: Canmore semi-anthracite, Greenhill bituminous and Coal Valley sub-bituminous. The results, given in Table 19, indicate there is no advantage to be gained by prolonged mixing when the temperature of mixing is sufficiently high. The briquettes become a little more dense, but there is not sufficient difference to warrant the increased time. The results also show that the time required for mixing is the same for all coals, although it varies with the viscosity of the binder.

T A B L E X I X.

Time of Mixing.

Run	Temp. Coal	Temp. Mix.	Temp. Press	Moist. %	R. L. %	Specific Gravity Apparent	Specific Gravity Real	Voids %	Time of Mixing
7200 g. Sterco + 800 g. McGillivray Creek, Screen Analyses #16 Mixing Ratio of binder 7 I.B.B. (asphalt)									
550	93	104	93	7.3	3.0	1.25	1.44	13.4	5 mins.
551	93	110	91	6.3	2.7	1.27	1.45	12.5	10 "
552	95	115	91	5.7	2.8	1.27	1.44	11.9	15 "
553	100	118	93	5.1	3.1	1.28	1.45	11.6	25 "
Canmore coal, Screen Analyses #41, Mixing Ratio of binder 6 I.B.B. (asphalt)									
739	100	128	75-80	3.7	6.7	1.20	1.33	9.4	5 "
740	100	133	85	4.1	6.0	1.21	1.33	9.2	10 "
741	100	131	80	4.0	5.6	1.21	1.33	9.2	15 "
742	100	131	82	2.8	5.8	1.20	1.33	9.6	25 "
Greenhill Coal, Screen Analyses #43, Mixing Ratio of binder 6 I.B.B. (asphalt)									
751	100	120	80	4.7	4.1	1.25	1.40	10.9	3 Mins.
752	100	122	82	4.9	3.6	1.25	1.40	10.6	5 "
753	100	121	80	4.8	2.3	1.26	1.40	9.7	10 "
754	100	118	76	5.6	3.0	1.26	1.40	10.1	15 "
755	100	123	75	5.3	2.8	1.26	1.40	9.6	25 "

(2) Temperatures of Mixing. Experiments have shown that the temperatures of mixing and pressing have a very marked effect upon the quality of the briquette and should be governed to suit the requirements of the binder.

The temperature of mixing should be high enough to render the binder quite fluid and thus insure that every particle of the coal becomes covered with binder. The temperature required will be related to the softening point of similar binders. But it cannot be said that the optimum temperature for different binders will be a certain number of degrees above the softening point of that binder, because the viscosity of one binder may decrease much more rapidly, with rise of temperature,

than of another. It has been found in the experimental work that the temperature of mixing must be varied to give the same desired low viscosity in every case. The maximum viscosity that can be used will be fixed by the time allowable and power available for mixing. At the same temperature a longer period of mixing with a viscous binder may give as thorough mixing as a shorter period with a less viscous binder.

In a commercial plant, the relative cost of increased temperatures will be considered on the one hand against the relative cost of increased time and power on the other.

Table 20 gives a comparison of the softening point of the typical binders used here with the temperatures at which the viscosity of each is the same.

T A B L E X X.

Comparison softening Point & Relative Viscosity.

	Softening Point (R. & B.)	Relative viscosity (Torsion Viscosimeter degrees damping)
L.P.	49.0°C	90-95°
S.C.T.P. Approx.	50.0°C	100-105°
H.C.T.P.	72.6°C	115-120°
I.B.B. (asphalt)	64.5°C	120-125°

It has been found from the experiments that the temperatures of mixing are in the same order as the relative viscosities. Thorough mixing is achieved with soft coal tar pitch at about 100°C, whereas a temperature of 120° to 125°C is required for I.B.B. (asphalt). Tests were made with different coals and binders to study the effect of varying the temperatures of mixing, but comparative results of the experimental work are not given, because no two binders require the same procedure to give the best results. The series given in Table 21, made with Coal Valley coal and Imperial Briquette Binder (asphalt) illustrate

the results obtained. It will be noted that the rattler loss increases with the lowering of the temperature of mixing.

T A B L E X X I.

Temperature of Mixing.

7200 g. Coal Valley coal, 800 g. McGillivray Creek coal; Screen Analysis 26; M: R. Binder 5 I.B.B. (asphalt) Mixing Ratio of water 8. Time of Mixing - 5 Mins.

Run.	Temp. Coal	Temp. Mix.	Temp. Press	% Moist.	% R.L.	Specific Gravity Apparent	Real	% Voids.
630	110	116	94	5.0	5.3	1.25	1.49	15.9
631	110	116	95	5.3	6.9	1.24	1.49	17.2
632	87	103	94	6.9	7.4	1.25	1.49	16.5
633	75	97	94	7.2	8.9	1.24	1.49	17.2
634	with coal*	97	90	7.3	8.5	1.25	1.49	16.7
635	"	92	95	6.9	10.8	1.24	1.49	16.8
636	"	79	88	7.8	29.0	1.25	1.49	16.6
637	"	63	64	7.2	87.4	1.24	1.49	17.0

(3) Temperature of Pressing. It is generally accepted that the higher the temperature of pressing, other conditions remaining the same, the better the quality of the briquette at the moment of pressing. This is because the binder at this temperature is less viscous and will squeeze into the voids more readily. Thus it will be clearly seen that as the temperature increases from a low temperature, the amount of voids will rapidly decrease until a point is reached when there will be practically no change. This is similar to the curve obtained for the relation between voids and pressure when the temperature is maintained constant.

The results obtained in the experimental work do not always conform to the above theoretical behaviour, but this can be explained by the difficulty of maintaining all other factors constant.

There is an upper limit, however, for the temperature of pressing, since at high temperatures the briquettes may not have suffi-

* See footnote page 42.

cient coherence to prevent the briquettes expanding and falling apart when the pressure is released, or being damaged in falling on to the cooling belt. This may offset any advantage to be gained from increased density. When a mix is pressed at a high temperature, there is a greater tendency for it to adhere to the plungers and not only weaken the briquette but cause considerable trouble in pressing.

To determine the effect of the temperature of pressing, large batches were made up and thoroughly mixed at 125°C. The mixture was gradually cooled and small portions pressed at various temperatures. The rattler test could not be applied to such small quantities, therefore the apparent specific gravity which gives the comparative value of coherence was recorded. The typical series, given in Table 22, was taken from W. L. MacDonald's work. The briquettes show an increase in density with increase in temperature of pressing.

T A B L E X X I I.

Temperature of Pressing.

Greenhill coal and 6 M.R. S.C.T.P.

Temp of Pressing	Apparent Specific Gravity.
120°C	1.28
110°C	1.26
100°C	1.25
90°C	1.25
80°C	1.24
65°C	1.23

Table 23 gives results obtained in Run 679 under similar procedure as above, but with Canmore coal and 6 M.R. Imperial Briquette Binder.

T A B L E X X I I I.

Temp. Pressing	App. Sp. Gr.	Real Sp. Gr.	% Voids.
145°C	1.15	1.34	13.6
125°C	1.15	1.33	13.8
120°C	1.15	1.33	13.7
110°C	1.15	1.33	13.1
98°C	1.15	1.33	13.4

T A B L E X X I I I - continued.

Temp. Pressing	App. Sp. Gr.	Real Sp. Gr.	% Voids.
93°	1.14	1.32	13.4
89°	1.16	1.33	13.0
84°	1.15	1.32	12.9
75°	1.15	1.33	12.8
65°	1.15	1.33	13.2
60°	1.15	1.33	13.0

The reason these results do not show any marked variation may be:

(1) Because an excess of binder is present.
(2) Because of the higher pressures used.
(3) Because the series was made without water being present and a great deal of sticking which may have weakened some of the briquettes pressed at the higher temperatures.

It was then felt that the best indication of the effect of temperature of pressing would be the rattler test, so recently a number of runs were made up; one-half the run was pressed at one temperature, the other half was cooled and pressed at a lower temperature. The following table gives the typical results obtained. Similar results were obtained with other coals and binders.

T A B L E X X I V.

Temperature of Pressing.

I.B.B. (asphalt) Binder, H_2O

Run	Binder	Temp. Press.	% Rattler loss	Specific Gravity Apparent	Specific Gravity Real	% Voids.
698 (a)	5 M.R.	95°C	16.7	1.19	1.35	11.9
(b)	"	60°C	21.2	1.19	1.35	12.0
699 (a)	"	95°	15.2	1.19	1.35	11.8
(b)	"	77°	20.5	1.17	1.34	12.6
700 (a)	"	96°	11.5	1.18	1.35	12.1
(b)	"	67°	16.7	1.19	1.35	11.4
704 (a)	"	95°	16.2	1.17	1.35	13.1
(b)	"	75°	20.2	1.18	1.34	12.0
701 (a)	4 M. R.	96°	28.2	1.18	1.35	12.5
(b)	"	60°	28.2	1.18	1.35	12.3

T A B L E X X I V - continued.

Run	Binder	Temp. Press.	% Rattler loss	Specific Gravity Apparent	Specific Gravity Real	% Voids.
702 (a)	4 M.R.	94°	33.7	1.17	1.35	13.2
(b)	"	70°	35.4	1.18	1.35	12.7
703 (a)	"	72°	25.9	1.16	1.34	13.7
(b)	"	65°	28.1	1.16	1.34	13.6
705 (a)	6 M.R.	93°	6.7	1.20	1.34	11.6
(b)	"	68°	5.4	1.21	1.34	11.0
Coal Valley Coal						
748 (a)	6 M. R.	85°	5.3	1.15	1.41	18.5
(b)	"	55°	5.0	1.15	1.41	18.6
749 (a)	7 M.R.	80°	4.0	1.15	1.41	18.3
(b)	"	60°	4.8	1.15	----	----
750 (a)	8 M.R.	81°	1.9	1.17	1.40	16.5
(b)	"	55°	1.7	1.17	1.40	16.7

These results clearly show that the briquettes pressed at the higher temperature are best, except when an excess of binder is present, and then an increase in temperature of Pressing does not affect the quality of the briquette.

Effect of Increasing Pressure. The quality of the briquette, ~~besides other factors, depends upon~~ is influenced by the pressure to which it has been subjected. With the equipment available the maximum pressure obtainable was approximately two tons per square inch, as shown in spring calibration curves, Figure 1, page 5 a.

In the press used, the pressure can be varied in four ways:

(1) By adjusting the length of the spring.
(2) By varying the strength of the spring.
(3) By adjusting the clearance between the plungers.
(4) By varying the thickness of the briquettes.

An attempt was made to obtain data as to the effect of varying pressures upon the quality of the briquette. The difficulty experienced was that the range on any one spring, or at any one spring-setting, was not large enough to make extensive tests and other variations may be introduced when the above are changed.

To determine the effect of pressure, a batch of various sized briquettes was made, a series of various sizes was selected from these, and the edge thickness of each measured. A measure of the pressure to which each had been subjected is found by taking the width of the briquette from the length of the spring at the spring-setting used, plus the clearance between the plungers at their closest approach to one another. This gives the length to which the spring has been compressed and from the spring calibration curve the approximate pressure on the briquette can be determined. A further pressure due to friction between the briquette and the die-box exists, and will increase with increased thickness of the briquette. It has been considered, but no means of measuring it has been devised.

The time the pressure is on the briquette is a factor to be considered. It will depend upon the length of the spring, upon the size of the briquette and upon the clearance between the plungers. This has not been measured.

Table 25 gives the apparent specific gravity of sized briquettes and the calculated pressure to which each briquette has been subjected for Runs 468, 469, 480 and 481. These runs were made under similar conditions, except for pressure. The average rattler loss of the run is given for comparison.

T A B L E X X V.

Specific Gravity.

Run No.		468		469		480		481	
Spring Setting		12 1/2"		12 1/4"		12"		11 3/4"	
Press. Tons per sq.in.	Total Pressure Lbs.	Size Brqt.	Ap.Sp Gr.	Size Brqt	Ap.Sp. Gr.	Size Brqt.	Ap. Sp. Gr.	Size Brqt.	Ap. Sp. Gr.
1.70	12000					1 1/4"		1"	1.29
1.37	9600					1 1/8"	1.30	7/8"	1.29
1.30	9100					1"	1.30	3/4"	1.30
1.23	8600	22/16"	1.28			7/8"	1.30	5/8"	1.29
		21/16"	1.28						
1.15	8100	19/16	1.27	1"	1.28	3/4"	1.30	1/2"	1.29
1.08	7600			14/16"	1.275	5/8"	1.29		
				13/16"	1.275				
1.03	7200	1"	1.27	3/4"	1.27	1/2"	1.29		
				11/16"	1.265				
.97	6800			10/16"	1.265				
		13/16"	1.265	9/16"	1.260				
.91	6400			1/2"	1.26				
		11/16"	1.265						
.85	6000	10/16"	1.26						
.80	5600	1/2"	1.25						
		7/16"	1.24						
.74	5210	6/16"	1.24						
Av. R.L. % (17.7)⟶				16.2		11.3		10.9	

The series indicate that the rate of increase in the apparent specific gravity of the briquette is rapid at first until it approaches the specific gravity of the mix, after which it would take a large increase in pressure to make an appreciable change in density. The increase in specific gravity shows an increase in the coherence of the briquettes, as is also shown by the improvement in the rattler tests. There are several points that require further study, and plans are in progress for doing this.

Addition of Moisture. The almost universal practice in commercial

briquetting plants is to preheat the coal to drive off the moisture before the binder is added. Before pressing, however, steam is usually blown into the mix. In the laboratory the amount of moisture desirable in a briquette mix has been an uncertain point as many contradictory results have been obtained from time to time. This was therefore studied in some detail in order to determine: (1) The effect of the addition of water upon mixing and pressing; (2) if different coals behaved differently upon the addition of water; (3) if moisture helped to flux the mix.

It has been found that good briquettes can be made without the addition of water, but a serious difficulty is the tendency of a dry mix either to adhere to the plunger of the press, or to squeeze out at the sides as dust. When moisture is present, the briquettes press without difficulty and have a much nicer appearance, although when too much is present, free water squeezes out around the plungers and gives briquettes that are of good quality, but steamy and dull in appearance.

The hotter the batch during the mixing stage, the more fluid the binder, and the less time and power is required to give thorough mixing, but if pressed at this temperature the briquettes fall apart upon leaving the press. The addition of water has been found to be a simple and satisfactory method of preventing this by cooling the mix from the temperature most satisfactory for mixing to the temperature most satisfactory for pressing. If there is to be free moisture present in the batch at the press, the temperature then cannot exceed 100°C.

The above tendencies have been more marked with lignite pitch and asphalts than with coal tar pitches.

The results obtained in the experimental work show that the nature

of the coal is an important factor in determining the amount of moisture desired in the mix.

N. H. Atkinson found, when working with Greenhill bituminous coal, that the addition of any moisture to the mix weakened the briquette very markedly (Carbonizing & Briquetting, p. 41). later, W. L. MacDonald, when testing the effect of the addition of steam upon the quality of the briquette obtained similar results, as is shown in Table 26.

T A B L E X X V I.

Addition of Steam - Greenhill Bituminous coal.

Run	M. R. Binder	Moisture	% Rattler loss.
208	6 S.C.T.P.	None	17.8
207	"	Steam	24.9
264	7 S.C.T.P.	None	21.0
265	"	Steam	24.1
266	"	None	15.8
267	"	Steam	26.2

In the recent work entirely concordant results have not been obtained, but the results, as shown in Table 27, indicate the same tendency. This is shown especially by the specific gravity determinations.

T A B L E X X V I I.

Addition of Water - Greenhill Bituminous coal.

Run	M. R. Binder	% Moist.	% R.L.	Specific Gravity Apparent	Real	Voids %
711	5 I.B.B. (asphalt)	1.0	10.6	1.25	1.39	10.0
729	"	1.9	9.6	1.25	1.38	9.9
712	"	5.0	16.5	1.23	1.40	11.7
713	"	8.1	14.7	1.23	1.41	12.6
714	6 S.C.T.P.	2.0	32.2	1.26	1.41	10.6
715	"	5.1	25.7	1.25	1.41	11.0
716	"	6.2	25.9	1.25	1.41	11.3

On the other hand the best results were obtained with sub-bituminous coal when the mixture going to the press contained 3 - 7% of moisture, and it was immaterial whether the water was added before or after the binder, except with regard to temperature control. It has been observed that, when more than this amount of water was present, a certain part of it squeezed out at the sides as free water

Table 28 gives results when varying amount of water was added to the mix.

T A B L E X X V I I I.

Addition of Water - Sub-bituminous coal.

8000 g. Sterco + 2.9 M.R. Brazeau dust, water and 7 M.R. S.C.T.P.

Run	M.R. Binder	Water added	* % Moisture in Briquettes	% Rattler loss	Apparent Sp. Gr.
	A Water added before binder.				
424	7 S.C.T.P.	0.0	3.3 (?)	24.5	1.26
423	"	1.4	1.7	23.5	1.26
422	"	2.9	1.3	20.8	1.35 (?)
421	"	4.3	3.4	17.5	1.28
420	"	5.8	3.5	13.8	1.31
418	"	7.3	5.2	14.5	1.30
417	"	8.7	4.7	12.3	1.33
416	"	10.2	2.8	16.7	1.32
415	"	11.6	7.8	14.9	1.32

* See footnote page 54.

TABLE XXVIII - continued.

B. Water added after binder.

Run	M.R.Binder	Water added	% Moisture in Briquettes	% Rattler loss	Apparent Sp. Gr.
425	7 S.C.T.P.	1.5	3.7	20.6	1.27
426	"	2.9	4.1	19.3	1.27
436	"	4.4	4.9	16.6	1.27
437	"	5.8	5.4	11.9	1.28
438	"	7.3	6.7	12.9	1.15 (?)

TABLE XXIX.

Addition of Water - Sub-bituminous coal.

Run	Coal	M.R.Binder	% Moisture in Mix	% Rattler loss	Specific Gravity Apparent	Real	Void %
724	Coal Valley	5 I.B.B.(asphalt)	3.2	15.0	1.22	1.46	16.4
725	"	"	5.3	9.2	1.23	1.48	17.1
723	"	"	7.4	8.5	1.22	1.47	17.2
726	"	6 S.C.T.P.	1.8	85.2	1.21	1.49	19.2
727	"	"	3.9	53.4	1.22	1.49	18.0
728	"	"	6.1	37.8	1.23	1.49	17.6

Only a few tests have been made to study this question in relation to Canmore semi-anthracite coal, and considerably more is required before definite results can be given.

Table 30 gives results to date.

TABLE XXX.

Addition of Water - Semi-anthracite coal.

Run	Coal	M. R. Binder	% Moist. in Mix	% Rattler loss	Specific Gravity Apparent	Real	Voids %
717	Canmore	5 I.B.B.(asphalt)	2.0	19.7	1.19	1.33	10.4
718	"	"	6.0	10.6	1.18	1.33	11.3
719	"	"	7.3	10.4	1.18	1.33	11.5
720	"	"	2.0	48.7	1.20	1.35	11.3
721	"	"	5.2	36.1	1.20	1.35	10.8
722	"	"	8.6	42.5	1.20	1.35	11.5

* In these results the % moisture in the briquette was taken rather than % moisture in mix, and may not be the correct amount in the mix as it went to press.

A possible explanation for the difference in the effects of the addition of water upon different types of coal can be found in the resistance they offer to being wet with water.

Weathering Tests.

To determine the weathering properties of briquettes made with various binders, samples of the briquettes were exposed to the weather for several months in open boxes. At the end of the period they were brought into the laboratory, air-dried to normal condition and a rattler test made.

A comparison of the rattler loss after exposure with the original rattler loss on a sample from the same run gave a measure of the weathering properties of the briquettes.

This test is much more severe than the briquettes would receive in commercial practice. Table 31 gives typical results obtained.

TABLE XXXI.
Weathering Tests.

Run	Coal	M. R. Binder	Original Rat. loss	Rattlerloss after exp.	Remarks.
Exposed March 2/25 to June 18/25					
472	Sterco	7 S.C.T.P.	17.3	29.6	Poor & pitted
475	Sterco & McG. Ck.	6 S.C.T.P. & sawdust	12.7	40.3	"
473	Sterco	6 S.C.T.P. & 1½ Flour	6.2	26.4	Poor
484	Sterco & McG. Ck.	6 S.C.T.P.	25.0	39.6	Fair
486	"	9 S.C.T.P.	11.9	14.9	Good
492	"	8 S.C.T.P.	9.2	22.0	"
496	"	6 S.C.T.P. & straw binder #65	14.2	40.5	Poor & pitted
497	"	6 S.C.T.P. & straw binder #66	7.6	25.9	Fair
498	"	6 S.C.T.P. & straw binder #67	13.5	47.0	Dull & pitted
499	"	8 S.C.T.P. & 1 waterglass	19.0	34.0	Badly pitted
501	"	8 S.C.T.P. & Trent process	8.8	13.3	Good

T A B L E X X X I - continued.

Run	Coal	M.R.Binder	Original Ratt. loss	Rattler loss after exp.	Remarks
	Exposed March 2/25 to June 18/25 - continued.				
515	Greenhill	6 S.C.T.P.	22.9	26.4	Excellent
518	"	4 S.C.T.P. & 1½ Flour	10.0	22.5	Fair
	Exposed Jan. 8/26 to April 10/26.				
666	Canmore	6 asphalt (Canmore)	8.3	13.7	Fair
661	"	6 asphalt (I.B.B.)	3.1	5.0	Good
683	"	6 asphalt (Wainwright crude oil)	17.1	20.8	"
676	"	6 asphalt (McMurray bitumen)	11.6	14.6	
	Exposed March 13/26 to April 10/26				
736	Coal Valley	6 Crude McMurray bitumen and 1½ flour	1.4	2.1	Excellent
738	"	"	5.0	2.5	"

The results indicate: (1) That briquettes made with asphalt binder weathered better than those made with other binders; (2) briquettes made with flour and crude McMurray bitumen were excellent, although the period of weathering was shorter; (3) briquettes made with Greenhill bituminous coal and soft coal tar pitch as binder weathered very well; (4) Washing the coal by the Trent process appears to have improved the weathering qualities of the briquettes; (5) Briquettes made with a sawdust, straw, flour binder and waterproofed with S.C.T.P. were on the whole poor.

F i r i n g T e s t s.

Samples of various batches of briquettes were placed on a bed of glowing coals, in either a furnace or McClary heater, and full notes made on their readiness of ignition, kind of flame, nature and amount of smoke, retension of shape and strength of the briquette at various stages during combustion.

It is obvious that the burning quality of the briquettes depends upon the nature of the coal and of the binder from which they are made. The coal cannot be controlled, but a binder with desirable burning qualities can be chosen.

The results of firing tests on briquettes made from Greenhill bituminous coal, carbonized lignite and raw lignite, and with coal tar pitch and asphalt as binder, are given in "Carbonizing and Briquetting".*

Briquettes made with sub-bituminous coal do not stand up well when thrown into a hot fire. Considerable work was done to overcome this by blending it with a coking bituminous coal. The results showed that when 10% of bituminous coking coal was added, the briquettes had excellent burning qualities. They retained their shape in fire and were strong enough to withstand stirring while burning.

The following observations have been made on the burning properties of binders. Bituminous materials volatilize at fairly low temperatures and give off considerable smoke. Coal tar pitch produces more smoke than asphalts. This smoke has an odor of creosote which is sometimes considered objectionable, whereas the smoke of asphalt is not. Organic binders, such as starch, flour, sulphite liquor, etc., which do not volatilize until decomposed, produce little smoke. Inorganic binders produce no smoke.

* Atkinson, N. H. Carbonizing & Briquetting, Page 52.

S U M M A R Y.

The following summary gives the more important features of the briquetting investigation to date.

1. Improvements have been made in the equipment used, and in the technique followed in the making of briquettes, in the testing of briquettes and in the testing of binders. These changes have made it possible to make a series of briquettes under more uniform conditions, and to obtain more accurate and detailed information.

2. It has been found possible to improve the firing properties of briquettes made with a non-coking coal by blending with it a small percentage of coking material. Briquettes made with sub-bituminous non-coking coal, to which had been added 10% of coking bituminous coal, had excellent firing properties.

3. The importance of the sizing of the coal has been determined, and a method given for finding the optimum sizing for any coal and equipment.

4. The addition of moisture to the mix has been found to have a deleterious effect upon briquettes made with bituminous coal, whereas the addition of 3 - 7% of moisture improves the quality of briquettes made with sub-bituminous coal.

5. The temperature of mixing has been found to be related to the viscosity of the binder and should be at a temperature at which the binder has a low viscosity.

6. The quality of the briquettes has been found to improve the higher the temperature of pressing provided the briquettes do not adhere to the plungers and have sufficient coherence when they leave

the press to stand handling.

7. It has been found that if the temperature of mixing is such that the binder has a low viscosity, two or three minutes mixing after the binder has been added gives as good briquettes as mixing for a longer period.

8. The best single binder to date has been found to be asphalt. It has been found that good asphalts can be obtained from McMurray Bitumen and Wainwright crude oil.

9. Binders made from starchy or cellulosic material have good binding properties. They are not satisfactory alone, as they are not waterproof, but if pitch or asphalt is added, they make strong briquettes which are less smoky in the fire than briquettes made with pitch or asphalt alone.

C H A P T E R I I.

Physical Properties of Binders.

I n t r o d u c t i o n.

The specifications for the binder purchased by large briquetting plants seldom include more than two or three properties. For example, nature of binder (whether pitch, asphalt or etc.), solubility in some solvent and melting point or penetration. The investigations made to date indicate that it is not possible to make specifications on the above lines such that the more closely the binder conforms to the specifications the better its binding qualities are; nor that it is possible to state that two binders of the same material, with the same solubility, melting point and penetration, are necessarily equally good. In other words there are one or more other factors which affect the binding qualities of a binder. No definite conclusions have yet been reached in this section of the work, but the following have been studied: Specific Gravity, Melting (softening) Point, Penetration, Ductility, Viscosity, Tackyness, Free and Fixed Carbon and Mineral Matter, ~~and Natural Mixing Ratios of Binders.~~

Although a large number of determinations have been made on a variety of materials, only typical results are given for four characteristic binders, namely; a sample of asphalt known as Imperial Briquette Binder, received from the Montreal refineries of the Imperial Oil Company,

Footnote: The experimental work in Chapter II was done by W. L. MacDonald, Session 1922-1923, but is being submitted here in an attempt to link up the physical properties of a bituminous substance with the procedure followed in making briquettes with it as binder.

two samples of coal tar pitch, one hard and one soft, secured from the by-product coke oven plant at Sault Ste. Marie, Ontario, and a sample of Lignite pitch supplied by the Lignite Utilization Board of Canada from the carbonization plant at Bienfait, Saskatchewan.

It is possible with any of these typical binders to make excellent briquettes, but the conditions will necessarily vary with each because of the difference in their physical properties. A commercial plant will choose the most suitable binder from an economic viewpoint, and suit the procedure to that binder. The supply of binder will require to be uniform and to comply with the required specifications.

Properties Studied.

Specific Gravity. Two methods may be employed to determine the specific gravity of bituminous materials depending upon their nature. For materials that are hard enough to be broken and handled in fragments at room temperatures, the displacement method is applicable, while for semi-solids the specific gravity should be determined by using a pyknometer.

Table 32 gives the specific gravities, as determined with the pyknometer method, according to the A.S.T.M. tentative standard procedure, D 70-20 T.

TABLE XXXII.

Specific Determinations - A.S.T.M. Tentative Standards 1923 p.490

I.B.B. (asphalt)	(1.0540 (1.0543	= 1.054
L.P.	(1.1056 (1.1103	= 1.108
S.C.T.P.	(1.2480 (1.2478	= 1.248
H.C.T.P.	(1.254 (1.257	= 1.256

Specific gravity determinations of bituminous materials are valuable in (1) identifying the bituminous material; (2) for controlling uniformity of supply from a given source; (3) *for calculating the weight of a given volume or conversely calculating the volume of a given weight of material, because bituminous materials are commonly purchased and used both upon a weight and volume basis.

In briquetting, when the binder is used as mixing ratio by weight, a given weight of binder of low density will cover a greater surface than the same weight of a denser material, other factors being constant.

Bituminous materials increase in specific gravity as the total bitumen decreases, and a high specific gravity usually indicates the presence of mineral matter or free carbon.

Softening Point (Melting point). The softening point of bituminous materials takes place at no definite moment or temperature, but as the temperature rises the material changes from a brittle or exceedingly thick material to a softer and less viscous liquid. For this reason, determinations of the softening point must be made by a closely defined method, if the results are to be comparable.

Two methods for its determination are in common use in this country: (1) The cube method used mainly for coal tar pitches, and (2) the ring and ball method used for asphalts. The ring and ball method is the simplest, most convenient and most commonly used, so has been adopted for the bulk of the work here. Determinations have been made with both methods according to the procedure laid down by the A.S.T.M. standard method. Ring and Ball D 36-21, A.S.T.M. Standards 1921 p. 739. Cube D 61-20, A.S.T.M. Standards 1921, p. 743. Table 33 gives results

* The specific gravity of the material at the temperature used would require to be determined.

obtained.

T A B L E X X X I I I.

Softening Point Determinations.

Binder	Ring and Ball	Cube.
I.B.B.	64.5°C	- - -
S.C.T.P. Bbl. #1	46.5°C	66.2°C
#2	54.0°C	- - -
H.C.T.P.	72.6°C	81.2°C
L.P.	49.0°C	- - -

The softening point of any binder acts as a guide in determining the temperature at which the mixing and pressing should be done. Usually the mixing should be done at least 40°C to 50°C above the softening point of the binder used to obtain the best results, although this is influenced by the viscosity of the material. The temperature of pressing is governed by the temperature at which the briquettes are not too friable when they come from the press. If a binder softens at a very low temperature, the briquettes will have a tendency to soften on a hot day.

Penetration. Penetration is defined as the consistency of a bituminous material under known conditions of loading time and temperature. These conditions are usually 100 grams for 5 seconds at 25°C, the distance being measured in tenths of millimeters.

The penetration at any given temperature, however, does not serve as a complete guide to the character of the binder, because two materials may have the same penetration at one temperature, but give quite different results at another. A low penetration indicates a hard and usually a brittle binder, and a high penetration a soft binder at the temperature of the test. The following determinations were made on a New York Testing Laboratory Penetrometer, according to the method by

(expressed as the distance a standard needle vertically penetrates a sample of the material).

the A.S.T.M. standard method, D 5-21, A.S.T.M. Standards, 1921, p. 728.

T A B L E X X X I V.

Penetration Determinations.

Penetration in tenths of mms. Load = 100 grams. Time = 5 seconds.

Binder	20°C	25°C	30°C	35°C	40°C	45°C
I.B.B.	20	23	35	53	75	101
S.C.T.P.	6	34	65	110	- - -	- - -
H.C.T.P.	-	0	0	4	9	20
L.P.	14	23	50	100	- -	- -

The penetration tests show the binder which is most susceptible to temperature changes and also the temperature at which the greatest change takes place. The penetration also gives an indication of the character of the material at low temperatures. The range of temperatures over which penetration tests can be made is usually small (and confined to room temperatures).

Ductility. Ductility determinations were made on a Smith Ductility Machine, according to the tentative method adopted by the A.S.T.M. (Tentative Standards, 1923, D 113 - 22 T, p. 507). The results are expressed in the distance in centimeters a block of the material of standard shape and dimensions and at a standard temperature can be drawn out to before it fractures.

T A B L E X X X V.

Ductility Determinations at Various Temperatures.

Binder	15°C	20°C	25°C	30°C	35°C
I.B.B.	-	5.3	8	11.2	14.2
S.C.T.P.	0	78.0	-	-	-
H.C.T.P.	0	0.	0	0.	11.2
L.P.	0	4.3	7.2	-	-

Ductility determinations can only be made over a small range of temperatures, the temperature range being 15°C to 40°C. They are an

indication of the toughness of a binder in the briquette, especially when stored in warm places. The ductility of asphalts change very slowly for rise in temperature, whereas soft coal tar pitch changes rapidly.

Relative Viscosity. The determination of the viscosity of pitches and asphalts over a range of temperatures is a difficult problem, because the standard viscosimeters were not designed to test such viscous materials. Three types of viscosimeter has been used here, namely: (1) a Redwood, (2) a torsion viscosimeter and (3) a Stormer viscosimeter. None has been entirely satisfactory, and at present only relative viscosities can be determined. Considerable time was spent trying to standardize these instruments in terms of absolute viscosity by the use of liquids of known viscosity sugar solutions, glycerine solutions, castor oil, etc., but to date the work has not been successful because of the wide difference in viscosity between these solutions and the viscosity of the pitches and asphalts.

A few trial runs were made on a Redwood viscosimeter, but the viscosity could be determined with accuracy only at high temperatures, and the work with this machine was discontinued.

An instrument similar to the Doolittle Torsion Viscosimeter was then designed and constructed. Consistent results were not obtained until a number of alterations had been made. Later, with this apparatus consistent results were obtained on very viscous materials, through a range of 50°C to 60°C from a point 30° above the softening point of the material. The instrument is, however, easily put out of adjustment and great care is needed in its operation.

Details of Apparatus. The machine is of the torsion type, as shown in Figure 11. It consists of a brass cylinder A, 3" long and 0.8"

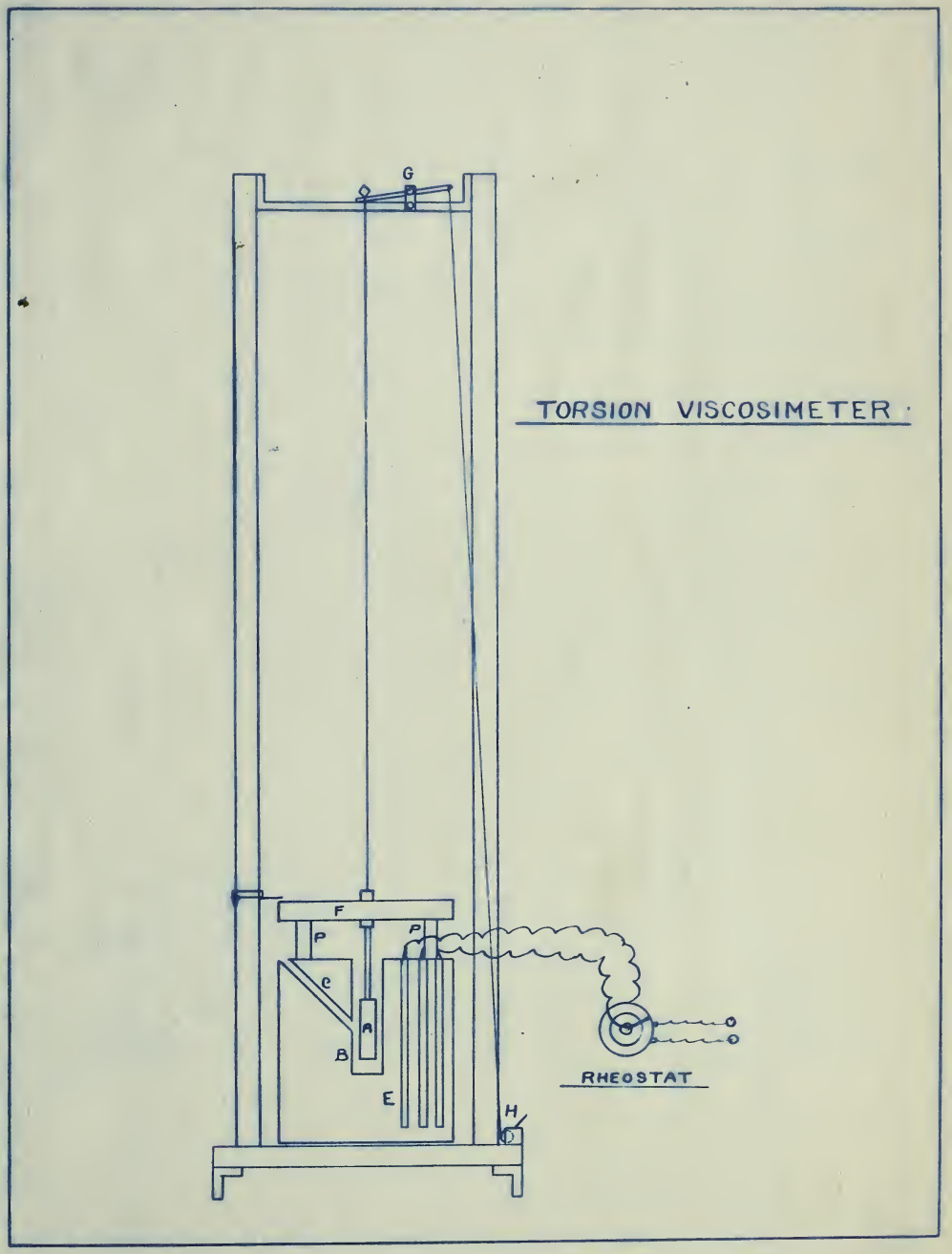


FIGURE XI.

in diameter, suspended in a container B, filled with the material to be tested. This container is elliptical in shape and has an apparatus for stirring the mixture in one end. There is a clearance of 0.35 inches between A and B. A tube, G, opens into the side of B to allow a thermometer to be placed in the material. The container is suppended in a large vessel D, 8 inches high and 9 inches in diameter. This is an oil bath heated by a set of heating coils, E. A uniform temperature is obtained by constantly stirring the oil. The cylinder A is attached by a spindle to a turned cast iron disc, F, 9.3 inches in diameter and 0.95 inches thick. The upper surface of the disc has a dial marked in ~~360°~~ degrees. The disc is suspended by a piece of 20 gauge piano wire 3 feet long to a lever at the top of the frame work. The upper end of the wire is attached to a small block which can be rotated and fits into a groove in the lever. The lever is pivoted at G and operated by a wire connected to the rachet H. When the machine is not in use, the disc rests on posts, P, but may be raised about one inch by means of the rachet and lever.

Procedure. The material to be tested is melted, then strained through gauze to remove lumps and foreign material, and placed in the container, then kept at the desired temperature for 15 minutes. The temperature can be regulated by the rheostat. The disc is raised and

allowed to come to rest, then lowered again. The wire is then twisted through 360° by turning the block in the groove. The disc is raised and it will oscillate. There is a damping effect on the oscillations due to the friction between the cylinder and material in the container. The measurement in degrees of the damping that occurs between the first and third oscillations is taken as the relative viscosity at that temperature. The relative viscosities, in the following table are the average of six readings, three of which were taken by rotating in a clockwise direction and three anti-clockwise.

T A B L E X X X V I.

Relative Viscosity Determinations.

Binder	75°C	80°C	85°C	90°C	95°C	100°C	105°C	110°C	120°C	130°C.
H.C.T.P.						122°	90°	60°	25°	14°
S.C.T.P.			109°		53°		27°	16°	9.5°	6°
L.P.	88°	61°	49°	35°	23°		15°	12°	8°	6°
I.A.						113°		80°	39°	21°

By comparing the viscosities of the various binders it will be seen that some binders will flow more readily than others at low temperatures, and also that there is a much greater change in certain cases for the same change in temperature. In general then, other things being equal, the viscosity of a binder will be an important factor in determining the time, temperature and power required for thorough mixing with that binder.

When water was added to the lignite pitch binder, little by little, up to 3%, the viscosity gradually dropped. When the water was increased to more than 3%, the viscosity increased and when 6% was present the viscosity was greater than that of the original binder. This is probably one reason why the addition of moisture to the mix gives a poor quality briquette. If more than 6% of moisture was present,* the binder

* Expressed as percentage of the binder, not of the mix.

would not spread over the coal so readily.

The results obtained are shown in Figure 12.

A Stormer viscosimeter was obtained recently, and tests run upon it. The results were not satisfactory because of the difficulty experienced with the temperature control. The oil-bath is too small to maintain a constant temperature over the period required for the cylinder to make one hundred revolutions in a viscous material. Relative viscosities at high temperatures can be made with this instrument, although consistent results were not obtained with either soft or hard coal tar pitch.

Tackiness. This is an arbitrary term used to define the relative cohesiveness of a binder. The operators in a number of briquetting plants speak of a desired quality in a binder as being the stickiness or tackiness. The determinations depended on the individual's sense of touch.

Various methods were divised for this determination with very little success. Eventually a piece of apparatus was designed which gave consistent results and relative determination were made on a few binders.

Apparatus. The apparatus is shown in Figure 13. It consists of a brass ball $1\frac{1}{2}$ inches in diameter resting in the mouth of a steel cone 1 inch in diameter. There are three small projections on the ball to hold it 1/32 of an inch from the cone and 3/8 of an inch hole through the centre to allow air to enter the cone and prevent a vacuum when the ball is being withdrawn. The determination is the pull necessary to draw the ball and cone apart when the space between is filled with binder. The measurement is made by suspending the ball from one side of a balance beam with a beaker from the other. Water is allowed to flow into the

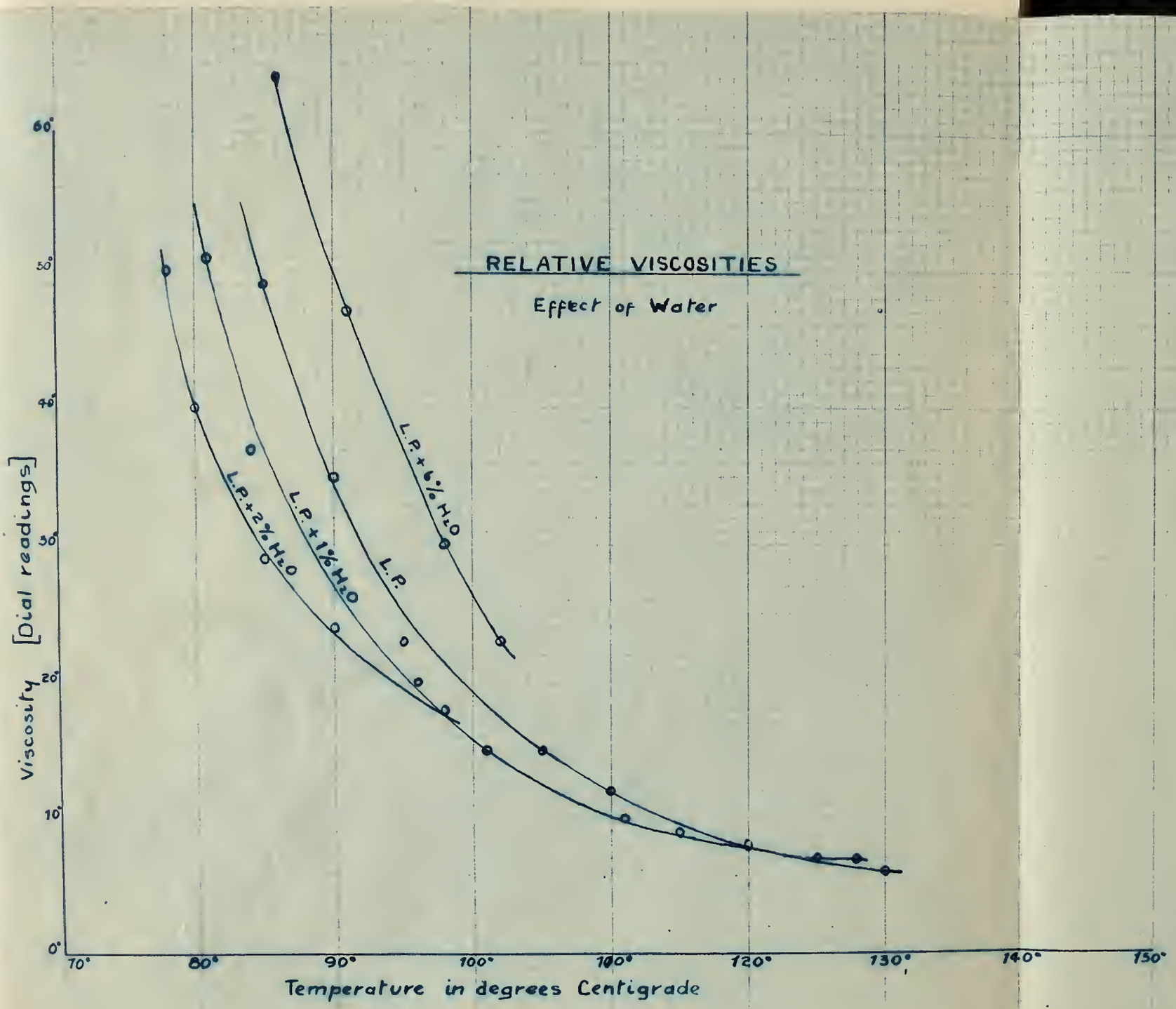

RELATIVE VISCOSITIES
Effect of Water
L.P. + 6% H2O
L.P. + 2% H2O
L.P. + 1% H2O
L.P.
Viscosity [Dial readings]
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
100°
110°
120°
130°
140°
150°
Temperature in degrees Centigrade

FIGURE XII.

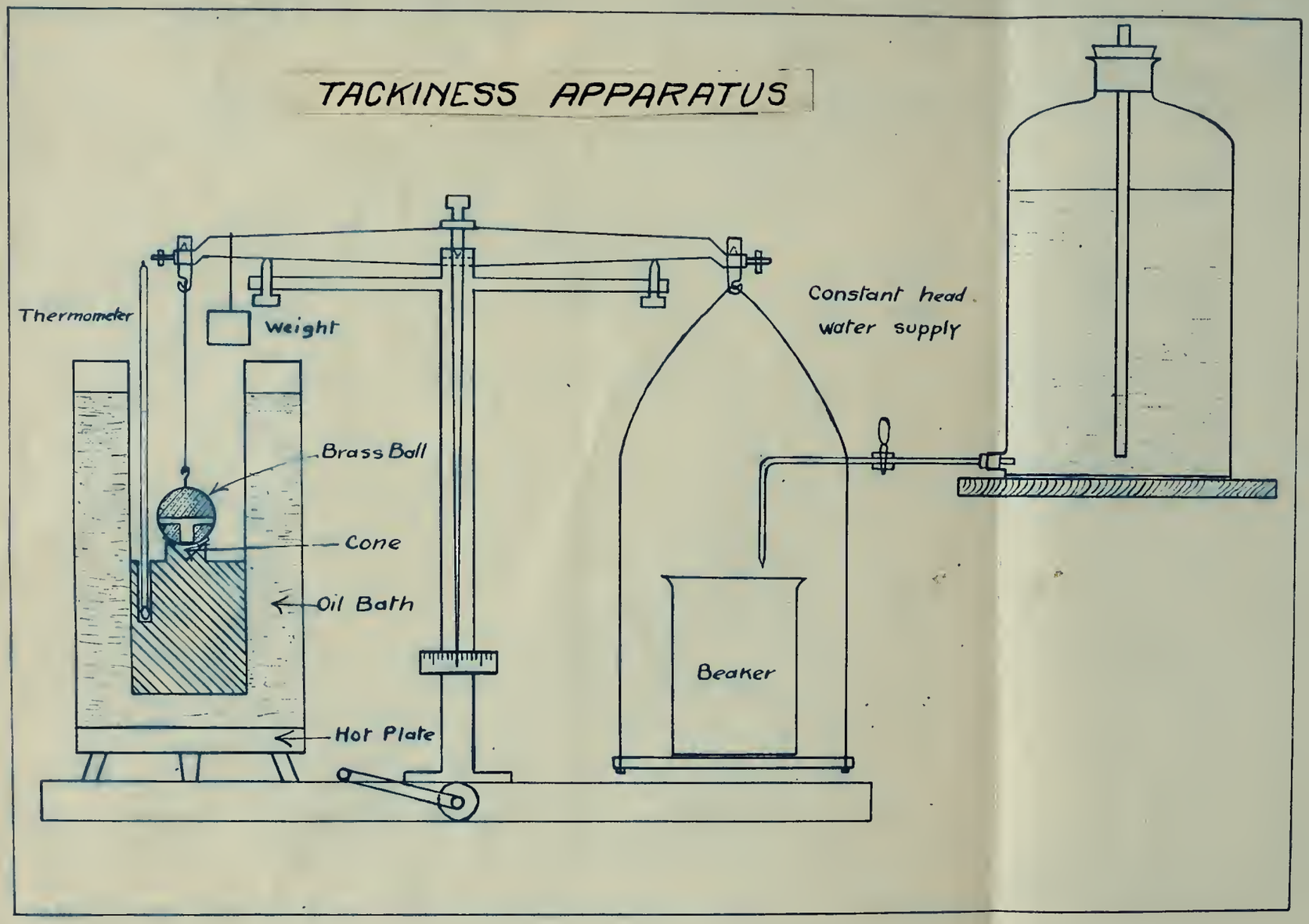

TACKINESS APPARATUS
Thermometer
Weight
Brass Ball
Cone
Oil Bath
Hot Plate
Beaker
Constant head
water supply

FIGURE XIII.

beaker at a constant rate of 100 g. per minute, and the weight noted when the ball and cone part.

The cone which is turned from the top of a heavy cylinarical piece of iron is filled with melted binder and the ball set in place on top. This is then placed in the water jacketed container and brought to a definite temperature on a hot plate. The temperature is recorded by a thermometer placed in a well beside the cone. The apparatus is then placed beneath the arm of a balance and the ball attached to it by means of a wire hook. The ball was previously balanced against the beaker on the opposite pan. The temperature is kept constant for 15 minutes, then the balance raised from its rests and water allowed to flow into the beaker. The water is shut off when the ball and cone part and the weight of water in the beaker determined. This was repeated at various temperatures.

The following table shows the relative values for various binders.

T A B L E X X X V I I.

Tackiness Determinations.

Binder	90°C	80°C	70°C	60°C	50°C	45°C	40°C
H.C.T.P.	8	14	56	110			
S.C.T.P.		5	9	20	52	100	
L.P.		3	6	12	29	50	87
I.A.	10	15	29	64	120		

These determinations give relative values as to the strength of the binder at various temperatures, and also the temperatures at which the binder becomes quite firm. These results may be of value in determining the temperature at which pressing could be done and the briquettes would be firm enough to handle when they came from the press.

Total Bitumen, Free Carbon, and Mineral Matter. In the analysis of pitches, tars and asphalts, the organic material insoluable in Carbon Disulphide is commonly known and reported as free carbon, the inorganic non-combustible, insoluable part as mineral matter, and the soluable portion as total bitumen.

The following table shows results of determinations made by a method similar to the standard method D 4-11 adopted by the A.S.T.M., 1921 p. 726.

TABLE XXXVIII

Binder	Total Bitumen %	Free Carbon %	Mineral Matter.%
I.B.B.	99.4	0.5	0.1
S.C.T.P.	79.8	20.1	0.1
H.C.T.P.	80.0	19.8	0.2
L.P.	85.9	13.9	0.2

In general, the material with the highest total bitumen will be the best binder, provided other factors are equal. A smaller mixing ratio of I.B.B. is required to make good briquettes than of the pitches and this no doubt is caused by the higher total bitumen.

The free carbon and mineral matter are impurities which are detrimental to the binder on account of requiring some of the binder to coat these minute particles.

Fixed Carbon. Fixed Carbon is the organic matter of the residual coke obtained upon burning hydrocarbon products in a covered vessel in the absence of oxygen.

The following table gives results of determinations made according to the standard method adopted by A.S.T.M.

T A B L E X X X I X.

Fixed Carbon Determinations.

Binder	Fixed Carbon. %
I.B.B. (asphalt)	23.6%
S.C.T.P.	32.0
H.C.T.P.	30.9
L.P.	16.4

The amount of fixed carbon present in a binder indicates the amount of coke that will be formed by the binder and available to cement the particles of coal together when the briquette is strongly heated. For this reason it may play an important part in the burning qualities of briquettes made with a non-coking coal. Coal tar pitches are sometimes preferred to asphalts because of this property.

C U R V E S F O R P H Y S I C A L T E S T S.

In Figure 14 are given the results obtained in the physical tests of the binders. It will be noted:

(1) That the range of temperatures for ductility and penetration tests is 15° to 45°C, for tackiness tests 40° to 90°C, for relative viscosity 75° to 130°C.

It has not been found possible to devise a series of different tests that can be carried out over the same range of temperature.

(2) That the ductility of soft coal tar pitch increases very rapidly with increase of temperature, whereas the ductility of asphalt and lignite pitch increases slowly with increase of temperature.

(3) That the tackiness and relative viscosity curves are similar which may indicate that tackiness is related to relative viscosity.

From the viscosity curves a comparison of the temperatures required for mixing with different binders can be had when the power required for mixing will be the same.

Penetration 1/10 mm's. ——— Relative Viscosity, degrees damping

Ductility in cm's. ------ Tackiness in grm's.

Temperature in °C.

S.C.T.P.

L.P.

I.B.B.

H.C.T.P.

B I B L I O G R A P H Y.

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